



US009422591B2

(12) **United States Patent**
Madura(10) **Patent No.:** **US 9,422,591 B2**
(45) **Date of Patent:** **Aug. 23, 2016**(54) **METHODS AND KITS FOR DETECTING**
MASTITIS(75) Inventor: **Kiran Madura**, Bridgewater, NJ (US)(73) Assignee: **RUTGERS, THE STATE**
UNIVERSITY OF NEW JERSEY,
New Brunswick, NJ (US)(*) Notice: Subject to any disclaimer, the term of this
patent is extended or adjusted under 35
U.S.C. 154(b) by 0 days.(21) Appl. No.: **14/234,749**(22) PCT Filed: **Jul. 26, 2012**(86) PCT No.: **PCT/US2012/048296**

§ 371 (c)(1),

(2), (4) Date: **Mar. 28, 2014**(87) PCT Pub. No.: **WO2013/016512**PCT Pub. Date: **Jan. 31, 2013**(65) **Prior Publication Data**

US 2014/0206010 A1 Jul. 24, 2014

Related U.S. Application Data(63) Continuation of application No. 13/190,869, filed on
Jul. 26, 2011.(51) **Int. Cl.****G01N 31/00** (2006.01)**G01N 33/53** (2006.01)**C12Q 1/37** (2006.01)**C12Q 1/68** (2006.01)**G01N 33/573** (2006.01)(52) **U.S. Cl.**CPC **C12Q 1/37** (2013.01); **C12Q 1/6888**
(2013.01); **G01N 33/573** (2013.01); **G01N**
2800/365 (2013.01)(58) **Field of Classification Search**CPC C07K 2319/07; C07K 2319/09; C07K
2319/10; A61K 48/005; A61K 48/0058
See application file for complete search history.(56) **References Cited****U.S. PATENT DOCUMENTS**4,303,752 A 12/1981 Kolehmainen et al. 435/8
5,091,306 A 2/1992 Citri 435/6.11
5,266,209 A 11/1993 Knight et al. 210/6916,294,363 B1 * 9/2001 Madura 435/183
6,660,469 B1 12/2003 Wright et al. 435/4
6,949,351 B1 9/2005 Squirrell et al. 435/15
7,329,529 B2 2/2008 Kapeller-Libermann 435/226
7,482,147 B2 1/2009 Glucksmann et al. 435/212
8,349,583 B2 1/2013 Green et al. 435/31
8,969,027 B2 3/2015 Bossmann et al. 424/9.1
2003/0092116 A1 5/2003 Chun et al. 435/69.1
2005/0123948 A1 6/2005 Claycomb et al. 435/6.11
2005/0287608 A1 12/2005 Madura et al. 435/7.9
2006/0124064 A1 6/2006 Fullam et al. 119/14.02
2007/0178545 A1 8/2007 Niles et al. 435/7.92
2010/0210022 A1 * 8/2010 Madura C12Q 1/37
436/86
2013/0130290 A1 5/2013 Green et al. 435/8**FOREIGN PATENT DOCUMENTS**GB 2001434 A * 7/1978 G01N 33/04
WO WO89/02929 4/1989**OTHER PUBLICATIONS**Chen, L. & Madura, K. "Evidence for Distinct Functions for Human
DNA Repair Factors hHR23A and hHR23B" FEBS Letters 2006
580:3401-3408.International Preliminary Report on Patentability from PCT/US2012/
048296, date Feb. 6, 2014.Bachmir, A. and Varshaysky, A. "The Degradation Signal in a Short-
lived Protein" Cell 1989 vol. 56 (6): 1019-1032.Boulanger et al. "Increased Nuclear Factor κB Activity in Milk Cells
of Mastitis-Affected Cows" J. Dairy Sci. 2003 vol. 86 (4): 1259-
1267.DeMartino et al. "PA700, an ATP-dependent Activator of the 20 S
Proteasome, Is an ATPase Containing Multiple Members of a
Nucleotide-binding Protein Family" The Journal of Biological
Chemistry 1994 vol. 269 (33): 20878-20884.Pyörälä, S. "Indicators of Inflammation in the Diagnosis of Mastitis"
Veterinary Research 2003 vol. 34:565-578.International Search Report from PCT/US2012/048296, date Oct.
15, 2012.

* cited by examiner

Primary Examiner — Lisa Cook(74) *Attorney, Agent, or Firm* — Licata & Tyrell P.C.(57) **ABSTRACT**Methods and kits for determining if one or more animals have
mastitis and for monitoring animals and the quality of the
milk they produce are disclosed. Kits and test assays dis-
closed are used to determine the quantity of proteasomes and
proteins thereof, the activity of proteasome enzymes, the
quantity of proteasome bound and regulating proteins, and
the quantity of ubiquitinated protein. Components and
reagents for use in the kits and assays are also disclosed.**1 Claim, 5 Drawing Sheets**

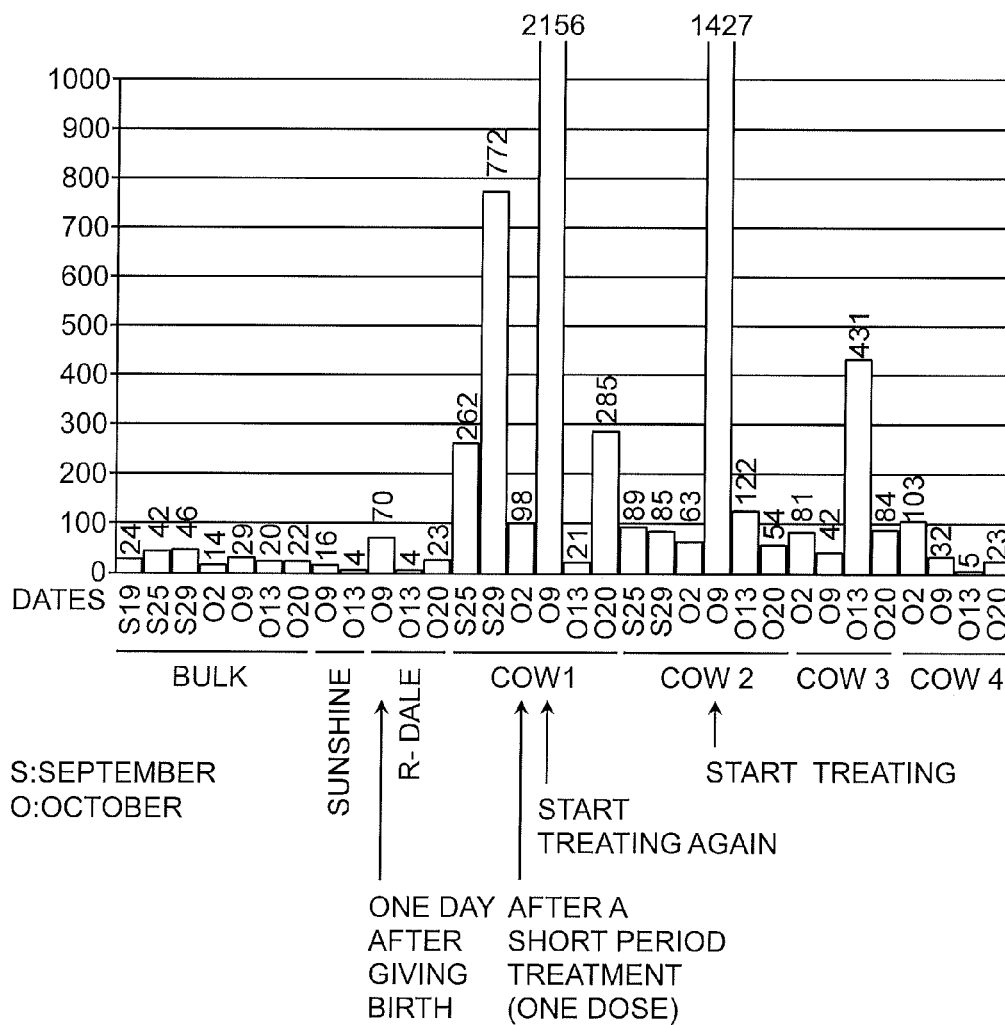


FIG. 1

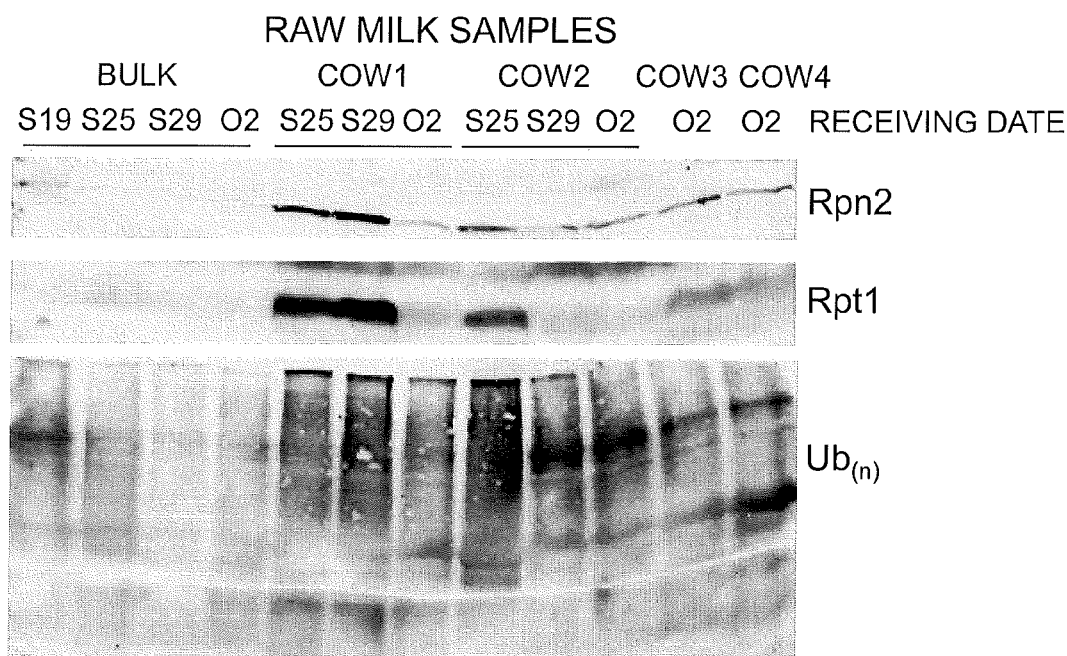


FIG. 2A

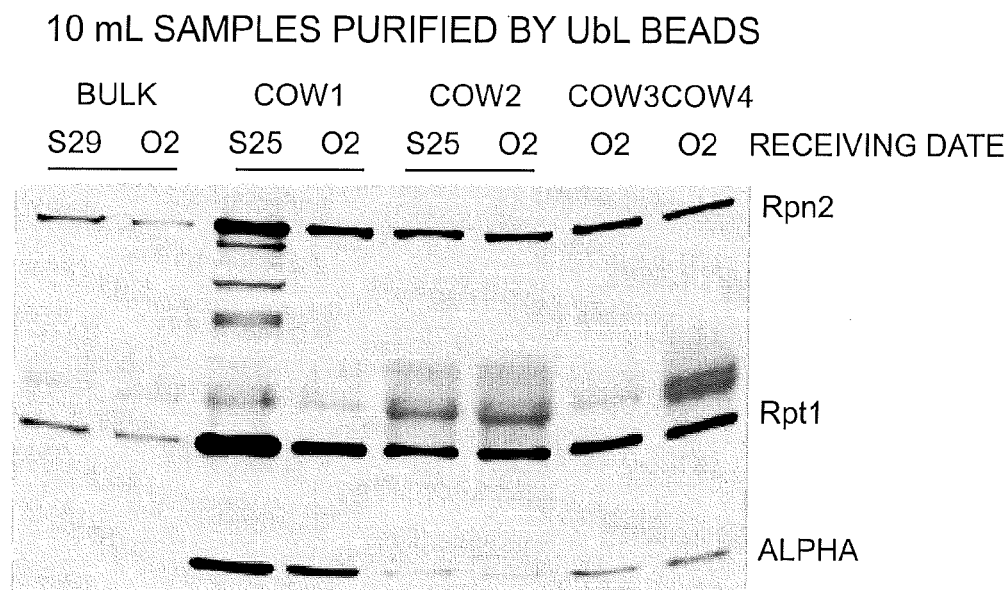


FIG. 2B

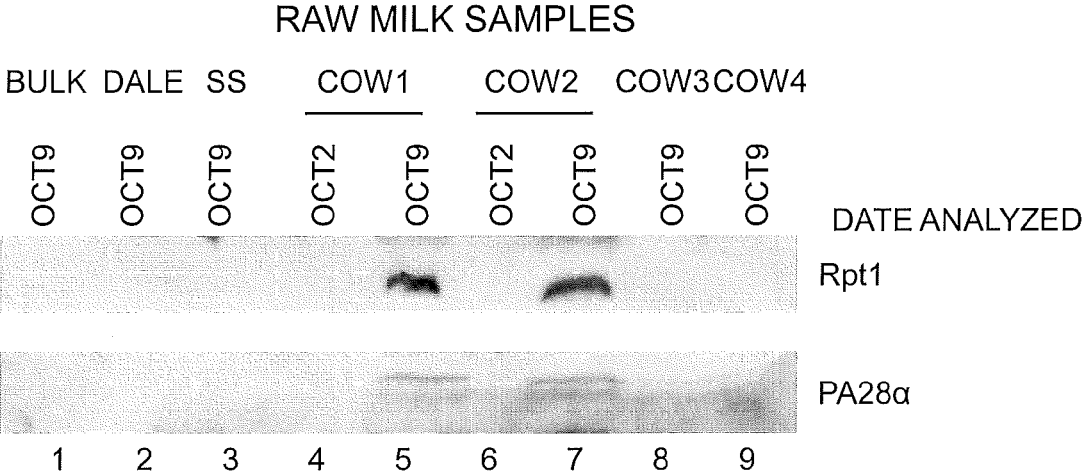


FIG. 3A

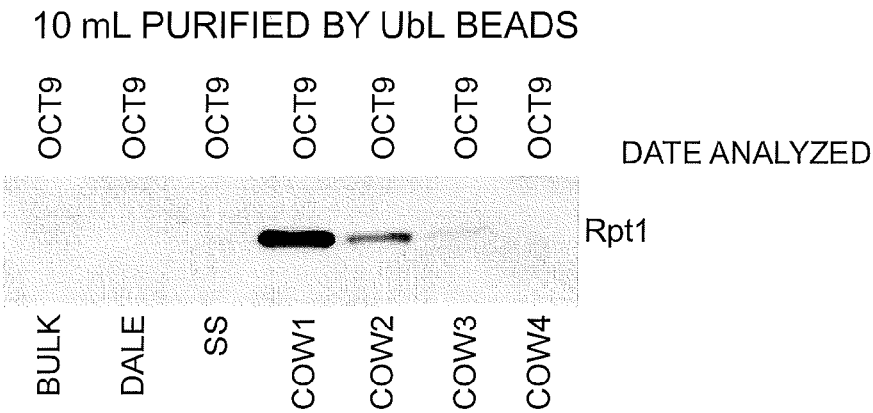
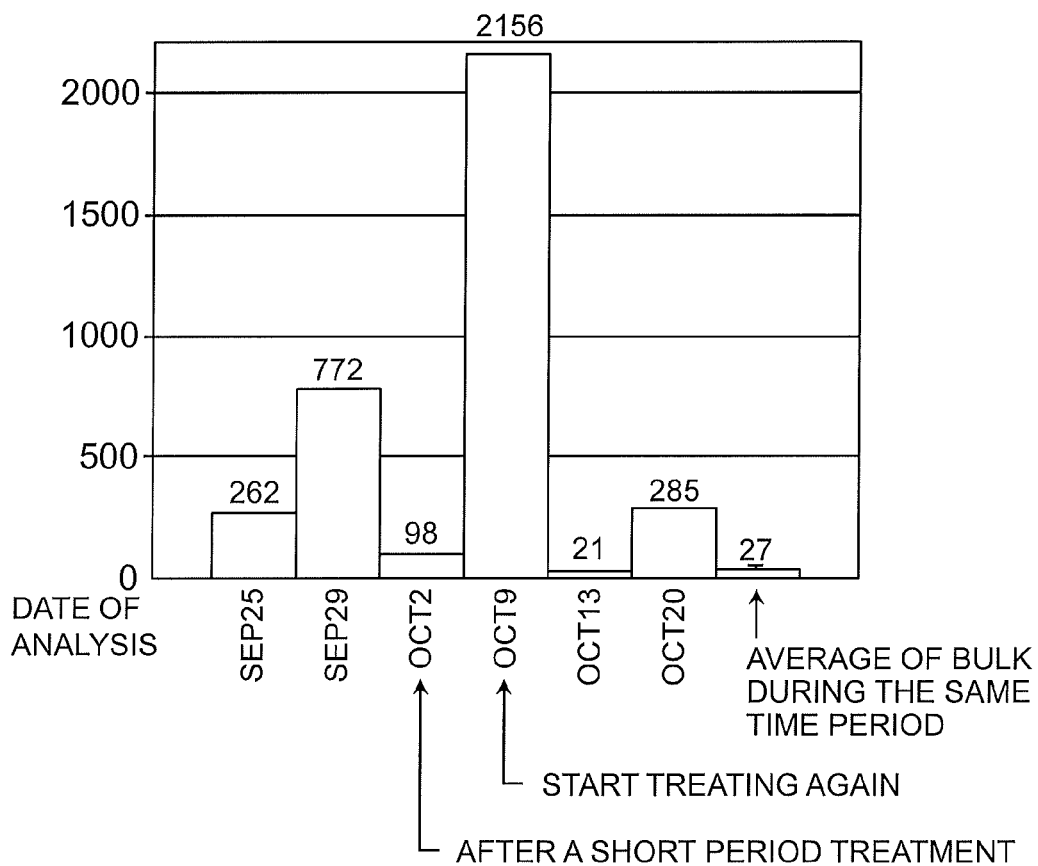
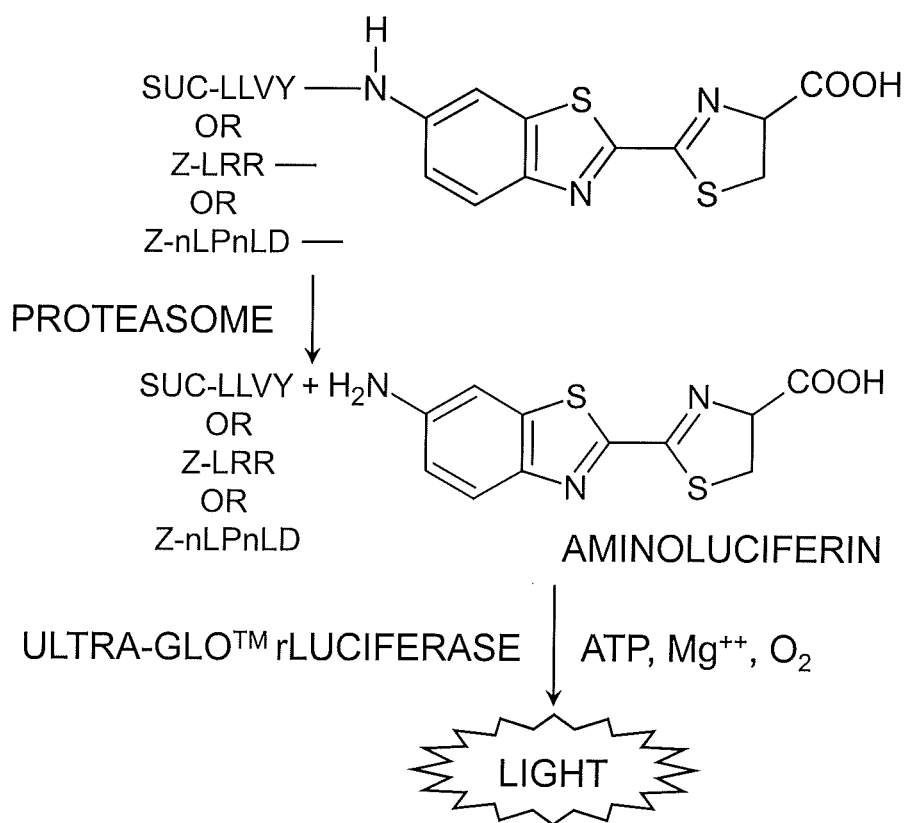


FIG. 3B

*FIG. 4*

**FIG. 5**

METHODS AND KITS FOR DETECTING MASTITIS

This invention was made with government support under grant number CA83875 awarded by the National Institutes of Health. The government has certain rights in the invention.

INTRODUCTION

This application is a U.S. National Stage Application of PCT/US2012/048296 filed Jul. 26, 2012 and claims the benefit of priority from U.S. application Ser. No. 13/190,869 filed Jul. 26, 2011, the contents of each of which are incorporated herein by reference in their entirety.

BACKGROUND OF THE INVENTION

Mastitis is a general term that describes inflammation in the milk glands and tissue lining the mammary gland/udder. Inflammation is a cellular- and organ-specific response to injury that can arise from a number of environmental events and pathogenic agents. Mastitis can be induced by physical injury (such as that caused by the milking apparatus), and from bacterial and fungal infections. Infections of the nipples, ducts and udders might be caused by *mycoplasma*, *pseudomonas*, *staphylococcus* and *streptococcus*, as well as coliforms such *Escherichia coli*. Probably more than a dozen different bacterial species, in addition to yeast and fungi, can cause mastitis in cow, sheep and goat. Yeast and fungal infections yield a sub-clinical form of infection and therefore may go undetected. However, it is not known if yeast/fungi can aggravate infection caused by coincident bacterial infection.

The living environment of dairy cows is conducive to infection, since the soil and manure are rich sources of bacteria. The animals are in frequent contact with the soil, and this is evident when one compares natural fluctuations in the sub-clinical infections during wet and dry seasons; wet environments cause higher levels of somatic cell count (SCC) values. Furthermore, the milking process is itself highly conducive to cross contamination. Therefore, animal management procedures play a key role in controlling the incidence of mastitis. Separation of infected animals, clean handling techniques, and well fitting vacuum suction cups can play an important role in minimizing the incidence of infection. Treatment of the affected animal includes antibiotics to eliminate the bacteria, and anti-inflammatory agents to reduce swelling.

In cows, the four teats drain separate compartments (quarters) in the udder, and the infection can migrate from one quarter to another in a single animal. Additionally, animal-to-animal and human contact can also extend the infection to other animals in the milk line. These issues are of considerable concern, since the milking process typically results in the collection of milk from many animals (50-200) in a common reservoir (bulk tank). Not surprisingly, a single heavily infected animal can compromise the quality of the entire milk output from a dairy facility. Culling chronically infected, unresponsive animals is a prudent measure. However, reduced milk output, poor milk quality, veterinary and health issues have a significant negative impact on the viability and productivity in dairy farms. In this regard, the technologies developed and described herein are expected to contribute to improving early diagnostics, minimizing cross-contamination, sequestering problematic animals, and monitoring efficacy of treatment.

Mastitis is characterized as clinical or pre-clinical mastitis. Sub-clinical mastitis is not visually detected (e.g., redness, soreness, swelling), and milk quality is not severely dimin-

ished. However, some changes may be observed, including clots and runny consistency of the milk. Redness, soreness and swelling of the teats are occasionally observed. Clinical mastitis can be mild or severe, based on the level of SCC in the milk. A heavily infected animal will display significant redness, soreness, and a hard teat, which will necessitate antibiotic treatment. The onset of mastitis can be rapid, and cause impaired breathing, failure to eat, and significantly increased body temperature. A systemic infection is considered grave, and the animal is removed from the milk line, and treated with antibiotics for approximately 3 days. Following the treatment, the animal is kept off the milk line until antibiotic levels in the milk are reduced. Some animals may tolerate chronic sub-clinical mastitis, although the extent of this occurrence and its effect of milk output and quality have not been carefully determined, because there is no straightforward way to measure it. Therefore, there is a need for detecting the early stage of infection to permit prompt removal of affected individuals before the bulk reservoir is affected. Because chronically affected individuals oscillate between high baseline of sub-clinical infection and full-blown infection, these candidates require constant monitoring, which is not possible with conventional methods, but can be easily achieved with the invention described here.

The standard assay for measuring mastitis in the dairy industry is to count the number of cells (originating from the cow), in the milk. This estimate is termed the somatic cell count (SCC). Specifically, the SCC reflects the levels of cells, including immune cells, such as leukocytes that are released from the lining and tissues of the udder of the infected animal, into the udder cavity. Although these cells are present in the milk, it is difficult to estimate their levels due to the difficulty of visualizing clear cells in the turbid milk suspension. The number of somatic cells in a given volume of milk (typically 1 ml) provides a semi-quantitative estimate of the degree of infection, because unaffected animals typically have low SCC levels. The SCC level may also be confounded by high levels of a pathogen, including bacteria, yeast and fungi, each of which is a causative agent in mastitis. There are a number of limitations of the SCC type assay. Due to turbidity, milk cell counts cannot be made, and instead the samples are tested at remote laboratories using independent measurements. The time lapse between the collection of a milk sample and the transmittal of the cell count information to the dairy farmer can exceed one month. This extraordinary delay in providing key information to the field agent or dairy farmer severely limits prompt action that might otherwise curtail the transmission of infection to unaffected animals. High level of SCC in the bulk tank deteriorates milk quality, and garners a lower price for the farmer. Furthermore, mastitis reduces milk output in the affected animal, and increases the likelihood of more frequent infections. Surprisingly, infected animals are only treated for a fixed term with antibiotics, and SCC levels are not typically monitored to confirm successful outcome. Consequently, an animal might be treated excessively, or not sufficiently. In the latter case, animals that respond poorly, or slowly to the antibiotic regimen, are likely to become chronic offenders that become drug resistant, yield poor quality of milk, incur large veterinarian expenses, eventually leading to the culling of the animal.

Federal and State guidelines allow up to about 7.5×10^5 somatic cells/ml of raw milk. This is the upper limit, and milk quality is negatively affected at such high SCC levels. Typical values in the bulk tank may range from $2-4 \times 10^5$ SCC. The level permitted by the European dairy industry is more stringent (4×10^5 somatic cells/ml).

There are currently two broadly available mastitis tests for monitoring milk quality. One assay, called the Somatic Cell Count (SCC) determines the level of somatic cells in the milk. The weaknesses of the SCC assay include inaccuracy, since it is negatively influenced by the presence of pathogens (the primary cause of mastitis) in the milk; insensitivity as it only provides a threshold value of the levels of somatic cells; and failure to provide early-diagnostic information, because the results are provided to the farm up to a month after the initial acquisition of milk samples. Moreover, an individual infected animal is not identified because SCC levels are typically measured in the bulk milk reservoir, which can contain milk from 50-100 cows. Therefore, this compromises the quality of milk in the bulk reservoir and delays detection of the affected animal. Moreover, advanced mastitis necessitates more aggressive treatment, prolonged withdrawal of the animal from the milk line, and a higher probability of generating a chronically affected individual, all of which represent significant economic liabilities to the farm. The SCC assay is hindered by the expense and delay of testing samples at a remote laboratory. Significantly, the delay prevents the implementation of prompt remedial action. Generally, the farmer/field agent recognizes symptoms in an affected animal and removes it from the milk line. However, this represents an action after the infection has occurred.

The second assay is termed the California Mastitis Test (CMT). In this method, milk from each quadrant of the udder is deposited into each of four shallow receptacles, to which a proprietary solution is added. Gentle mixing results in clumping of mastitis-positive samples. This is an imprecise assay that does not give any quantitative measurement of the level of infection. Moreover, the assay is quite insensitive, and does not detect lower levels of persistent mastitis.

While other assays have been suggested, these assays have not been developed for commercial use. For example, Pyörälä ((2003) *Vet. Res.* 34:565-578) suggests that ATP has a strong positive correlation with SCC and has been considered as an alternative to SCC as an indicator of mastitis. Similarly, GB 2001434 indicates that ATP levels correlate with somatic cell count numbers and can be used to determine the hygiene of milk or the health condition of cows. However, neither of these assays detects the level of proteasome activity via a proteasomal substrate or hydrolysis of ATP.

Clinical mastitis causes greater than \$2 billion in directly attributable losses for the dairy industry. However, this is an underestimate, because the financial loss caused by low quality milk and poor yield from sub-clinical cows, treatment of affected animals, withdrawal from the milk line, and occasional culling of ill animals is not estimated. Accordingly, there is a need in the art for rapid, reliable and accurate tests for detecting mastitis.

SUMMARY OF THE INVENTION

The present invention features methods and kits for detecting and monitoring mastitis. In one embodiment, the method of the invention involves the steps of (a) performing a test assay for determining the level of proteasomes present in a test sample of milk collected from one or more animals, and (b) comparing the level of proteasomes present in the test sample with a standard level of proteasomes in a control sample of milk, wherein an increase in the level of proteasomes present in the test sample relative to the standard level of proteasomes present in the control sample of milk indicates one or more animals has mastitis. In certain embodiments of this method, the test assay for determining the level of proteasomes present in the test sample detects proteasome activ-

ity in the sample by, e.g., measuring the level of conversion of a proteasome enzyme substrate to a product. Examples of such substrates include an ATPase substrate, a de-ubiquitinase substrate, or a substrate such as Suc-Arg-Pro-Phe-His-Leu-Leu-Val-Tyr (SEQ ID NO:8); Z-Gly-Gly-Leu; Suc-Leu-Leu-Val-Tyr (SEQ ID NO:9); Suc-Leu-Tyr; Ac-Arg-Leu-Arg; Boc-Leu-Arg-Arg; Bz-Val-Gly-Arg; Ac-Gly-Pro-Leu-Asp (SEQ ID NO:7); Z-Leu-Leu-Glu; and Ac-nLeu-Pro-nLeu-Asp (SEQ ID NO:6), which may be labeled with a fluorogenic label, luminescent label or a chromogenic label. In other embodiments of this method, the test assay for determining the level of proteasomes present in the test sample is an assay that detects nucleic acid molecules encoding proteins or an assay that detects proteins such as one or more proteasome proteins, one or more proteasome binding proteins, one or more proteasome regulating proteins, a nucleic acid molecule that encodes a proteasome protein, a proteasome regulating protein or a proteasome binding protein. In certain embodiments, the test assay for determining the level of proteasomes present in the test sample is an assay to determine the level of immunoproteasomes present in the test sample. In other embodiment, the test assay for determining the level of proteasomes present in the test sample is an assay to detect the level of ubiquitinated proteins in a sample or copper complex binding to proteasomes. A kit for carrying out this assay is also provided.

As another embodiment, the method of the invention involves the steps of (a) collecting a test sample of milk, (b) performing a test assay for determining the level of proteasomes present in the test sample, and (c) comparing the level of proteasomes present in the test sample with a standard level of proteasomes in a control sample of high quality milk or comparing the level of proteasomes present in the test sample with a standard level of proteasomes in a control sample of low quality milk; wherein an increase in the level of proteasomes present in the test sample relative to the standard level of proteasomes present in the control sample of high quality milk indicates the milk is of lower quality; an increase in the level of proteasomes present in the test sample relative to the standard level of proteasomes present in the control sample of low quality milk indicates the milk is of higher quality; a substantially similar level of proteasomes present in the test sample relative to the standard level of proteasomes present in the control sample of high quality milk indicates the milk is of high quality; and a substantially similar level of proteasomes present in the test sample relative to the standard level of proteasomes present in the control sample of low quality milk indicates the milk is of lower quality. A kit for carrying out this assay is also provided.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 shows the fold increase in proteasome activity in affected cow milk, as compared to normal healthy cow milk. Sunshine and R-Dale were young and healthy. COW1 was chronically infected. COW2 was injured. COW3 and COW4 were suspicious and under observation.

FIGS. 2A and 2B show the altered abundance of proteasome subunits in raw milk samples (FIG. 2A) and purified milk samples (FIG. 2B).

FIGS. 3A and 3B show the altered abundance of immunoproteasome subunits in raw milk samples (FIG. 2A) and purified milk samples (FIG. 2B).

FIG. 4 shows proteasome activity in a chronically infected cow over the course of a month.

FIG. 5 shows a depiction of examples of luminescent assays, wherein Suc-LLVY (SEQ ID NO:9), Z-LRR or Z-nLPnLD (SEQ ID NO:6) are attached to luciferin.

DETAILED DESCRIPTION OF THE INVENTION

The Ub/proteasome proteolytic pathway is required for efficient cell-cycle control, stress response, DNA repair, and differentiation (Glickman & Ciechanover (2002) *Physiol. Rev.* 82:373-428; Pickart (1997) *FASEB J.* 11:1055-1066; Varshaysky (1997) *Trends Biochem. Sci.* 22:383-387). Mutations in this pathway can cause pleiotropic defects because of its involvement in virtually all aspects of cell function. Consequently, the characterization of the Ub/proteasome pathway for the development of treatment for cancer and other malignancies is an area of active investigation (Voorhees, et al. (2003) *Clin. Cancer Res.* 9:6316-6325; Yang, et al. (2004) *Clin. Cancer Res.* 10:2570-7; Yang, et al. (2004) *Clin. Cancer Res.* 10:2220-2221; Rossi & Loda (2003) *Breast Cancer Res.* 5:16-22; Ohta & Fukuda (2004) *Oncogene* 23:2079-2088).

The 26S proteasome is composed of a catalytic (20S) particle and a regulatory (19S) particle. The structure and function of the 20S catalytic particle is conserved in evolution, and its compartmentalized organization ensures that the proteolytic activities are sequestered within the interior of the proteasome (Baumeister, et al. (1998) *Cell* 92:367-380). The large 19S regulatory particle interacts with the 20S particle to facilitate recognition, unfolding and degradation of ubiquitinated substrates (Glickman, et al. (1998) *Mol. Cell. Biol.* 18:3149-3162; Groll, et al. (2000) *Nat. Struct. Biol.* 7:1062-1067). Ubiquitin (Ub) is covalently attached to lysine side-chains in cellular proteins (Pickart (2000) *Trends Biochem. Sci.* 25:544-548). The ligation of Ub to proteins requires the action of three enzymes termed Ub-activating (E1), Ub-conjugating (E2), and Ub-ligases (E3) (Glickman & Ciechanover (2002) *supra*). The sequential addition of Ub moieties results in the formation of a multi-Ub chain, which facilitates protein degradation by promoting translocation of substrates to the proteasome (Gregori, et al. (1990) *J. Biol. Chem.* 265:8354-8357; Thrower, et al. (2000) *EMBO J.* 19:94-102).

Malignant conditions are frequently associated with altered abundance and stability of regulatory proteins. It is therefore likely that the expression of a unique repertoire of proteins underlies the transition from normal to abnormal growth. Proteasome activity has been found to be elevated in esophageal cancer and cancer cachexia (Wyke, et al. (2004) *Br. J. Cancer* 91:1742-1750; Zhang, et al. (2004) *World J. Gastroenterol.* 10:2779-2784).

It has been shown that the co-translational degradation of newly synthesized misfolded proteins requires the Ub/proteasome system (Schubert, et al. (2000) *Nature* 404:770-774; Reits, et al. (2000) *Nature* 404:774-778; Turner & Varshaysky (2000) *Science* 289:2117-2220). Moreover, translation elongation factor 1-alpha (eEF1A) is required for the efficient degradation of nascent polypeptide chains, especially in ATP-depleting conditions, and in the presence of protein synthesis inhibitors (Chuang, et al. (2005) *Mol. Cell. Biol.* 25:403-413). eEF1A expression is increased in certain cancers, e.g., T-lymphoblastic cancer (Lamberti, et al. (2004) *Amino Acids* 26:443-448; Dapas, et al. (2003) *Eur. J. Biochem.* 270:3251-3262), a result that reflects a more general response to aberrant growth (Ejiri (2002) *Biosci. Biotechnol. Biochem.* 66:1-21).

It has now been shown that the detection of proteasomes in milk can be used as an indicator of mastitis in a milk-producing animal as well as a measure useful to assess the quality of the milk. Proteasomes are found in the somatic cells found in

milk including the immune cells such as leukocytes which are present in increasing numbers as the level of infection progresses, as an animal goes from uninfected to severe mastitis. Additionally, the infectious organism responsible for mastitis also has proteasomes that can also be detected using distinct proteasome assays and antibodies.

Proteasomes are very robust by their nature and remain enzymatically active in milk. Thus, measuring the level of enzyme activity in a sample as compared to standard levels or ranges typical of uninfected, preclinical-mastitis, mild clinical mastitis, severe clinical mastitis and the like indicates not only a diagnosis of mastitis but also the severity of the condition. Proteasome enzyme activity assays are fast and simple and can be carried out with very little equipment or expense at the site where the milk is collected. When used in the context of dairy livestock, management and treatment of animals can be undertaken to maximize yield, minimize time off the line, and to improve the overall health and well being of the animals through early diagnosis and monitoring during treatment.

Likewise, because proteasomes are present in milk, they provide a useful target for detection by immunoassay, or as targets for detection of mRNA encoding proteasome protein components. In the case of immunoassay, the level of proteasome protein in a sample may be compared to standard levels or ranges typical of uninfected, preclinical-mastitis, mild clinical mastitis, severe clinical mastitis and the like to diagnosis mastitis and assess its severity. Similarly, the level of mRNA that encodes a proteasome protein in a sample may be quantified and compared to standard levels or ranges typical of uninfected, preclinical-mastitis, mild clinical mastitis, severe clinical mastitis and the like to diagnosis mastitis and assess its severity. These methods may be used to improve the productivity and health of animals.

Other methods of detecting proteasome levels include, for example, detection of levels of proteasome bound factors or mRNA encoding the same, detection of levels of proteasome regulatory factors or mRNA encoding the same, and levels based on interaction with organic copper complexes.

For the purposes of the present invention, the term "level of proteasomes present" is meant to refer to the quantity of proteasomes present. The proteasomes may be from the animal's somatic cells or from a bacteria, fungus and/or yeast organism infecting the animal. The level of proteasomes may be determined by direct quantification or by determining the level of proteasome enzyme activity or activity of enzymes associated with proteasome. The term "standard level of proteasomes in a control sample of milk from an uninfected animal" is meant to refer to a typical quantity or range of quantities of proteasomes found in a sample of milk from an uninfected animal, wherein the sample is of a known sample volume, preferably the same volume as being used in a test assay. The term "proteasome enzyme activity" is used herein to refer to enzymatic activity by one of the several proteasome enzymes present as part of the proteasome complex whereby a substrate is processed by the enzyme into one or more products which are distinguishable from the substrate. Proteasome enzymes include the chymotrypsin-like or chymotryptic protease, the trypsin-like or tryptic protease and the caspase-like, or post-acidic protease. The term "level of conversion of a proteasome enzyme substrate to a product" is meant to refer to the quantity of substrate converted to a product by an enzyme in a test period.

The proteasome contains three enzyme activities: 1) protease activity, 2) ATPase activity and 3) de-ubiquitination activity. Three different proteases perform the protease activity. These include the trypsin-like enzyme, the chymotrypsin

like enzyme, and the caspase-like enzyme. Each of these enzymes cleaves peptide bonds at the C-terminus of different types of amino acids.

In the enzyme assays disclosed herein, the level of enzyme activity is determined by measuring the cleavage or processing of a substrate into products. Typically, enzyme assays use labeled substrate in which the label becomes detectable after processing. In such case, the level of activity is indicated by measuring the amount of product produced. It is also possible to measure enzyme activity by using a labeled substrate in which the label is detectable when the substrate is unprocessed and becomes undetectable after processing. In such case, the level of activity is indicated by measuring the amount of substrate processed. As an alternative, Verma, et al. ((2000) *Mol. Biol. Cell.* 11(10):3425-39) refer to the identification of nucleotide-sensitive proteasome-interacting proteins by mass spectrometric analysis of affinity-purified proteasomes.

Protease Assays. As noted above, there are three different proteases, the trypsin-like enzyme, the chymotrypsin like enzyme, and the caspase-like enzyme, and each cleaves peptide bonds at the C-terminus of different types of amino acids. In its usual functioning in the cells, proteins are labeled for destruction by attachment to ubiquitin and delivered to the proteasome where the proteins are de-ubiquitinated and unfolded so that they can be moved into the proteasome and processed by the proteases. The three proteases of the proteasome are located internally in a proteasome structure and so the proteins to be cleaved are unfolded and translocated into the proteasome. The proteases recognize and cleave by hydrolysis peptide bonds which are at the C terminus of different amino acid residues. The trypsin-like enzyme cleaves after a basic amino acid residue. The chymotrypsin like enzyme cleaves after a hydrophobic amino acid residue. The caspase-like enzyme cleaves after an acidic amino acid residue. A detailed analysis of the amino acid sequence preferred by the hydrolytic activities present in the proteasome is described in the art (see, e.g., Dick, et al. (1998) *J. Biol. Chem.* 273:25637-25646).

In assays provided herein, substrates are used that are spontaneously processed by the proteasomes. Specifically, these substrates do not need to be attached to ubiquitin, or unfolded. To be spontaneously processed by a protease, the substrate must be of a size that it can enter the proteasome without the need for delivery proteins, de-ubiquitination, or unfolding. Thus, substrates that can be spontaneously processed are typically no longer in length than the length of a 3-6 amino acid peptide, and are no more than 13 Angstroms cross-wise so that it can freely enter the proteasome. The structure of the 20S proteasome from yeast at 2.4 Å resolution is known (Groll, et al. (1997) *Nature* 386:463-471). The crystal structure of the 20S proteasome from the yeast *Saccharomyces cerevisiae* was reported to show that its 28 protein subunits are arranged as a complex in four stacked rings and occupy unique locations. The interior of the particle, which harbors the active sites of the three proteases, is only accessible by two 13 Angstrom diameter axial pores.

To be processed, the substrate must include a peptide bond at the C-terminus of an amino acid residue. Accordingly, the general formulae for the substrates are $X-Y-A=Z$ for trypsin-like substrate, $X-Y-B=Z$ for chymotrypsin-like substrate and $X-Y-C=Z$ for caspase-like substrate, wherein X is a blocking moiety which prevents N-terminal proteases from processing the substrate, Y is absent or moiety which links X to A, A is a basic amino acid or moiety which forms a peptide bond with Z that is recognized and cleaved by the trypsin-like protease, B is a hydrophobic amino acid or

moiety which forms a peptide bond with Z that is recognized and cleaved by the chymotrypsin-like protease, C is an acidic amino acid or moiety which forms a peptide bond with Z that is recognized and cleaved by the caspase-like protease, $=$ is a peptide bond that links A, B or C to Z and that is recognized and cleaved by the protease, and Z is a label that is either undetectable when linked to A, B or C and becomes detectable when $=$ is hydrolyzed, or is detectable when linked to A, B or C and becomes undetectable when $=$ is hydrolyzed.

Typically, the substrates are N-terminally blocked linear peptides that are not folded and have a secondary structure and linked at their C-terminus to detectable labels by a peptide bond. Thus, according to the formulae above, the peptides are $Y-A$, $Y-B$ or $Y-C$ in which Y is 1-4 amino acids, A is an amino acid which is recognized by trypsin-like protease, B is an amino acid which is recognized by chymotrypsin-like protease, and C is an amino acid which is recognized by caspase-like protease. N-terminal blocking moieties are well-known in the art and include, but are not limited to, succinimide (Suc), (Boc), benzoyloxycarbonyl (Z) and benzoyl (Bz).

Detectable labels useful in the methods of the invention are well-known and include fluorescent, colorimetric and luminescent labels. Examples of fluorescent labels include 7-amino-4-methylcoumarylamide (AMC). Examples of luminescent labels include luciferin. Examples of colorimetric labels include copper complex reagents. Fluorescence may be measured using standard commercially available fluorometer equipment. Examples of fluorescence detectors include Turner 7000 (Sunnyvale, Calif.), Turner AQUAFLUOR (Sunnyvale, Calif.), and TECAN Genesis plate reader. Fluorescent, luminescent and colorimetric labels and methods of detecting and measuring quantities with them are well-known and readily understood by those skilled in the art.

As used herein, the terms "trypsin-like substrate" and "tryptic substrate" are used interchangeably and meant to refer to substrates which can be spontaneously processed by the trypsin-like protease which is also referred to as tryptic protease. Examples of amino acids recognized by trypsin-like protease, i.e. A amino acids, include the basic amino acids Arginine; Lysine; and in some cases Histidine. Examples of trypsin-like substrates include Ac-Arg-Leu-Arg-AMC; Boc-Leu-Arg-Arg-AMC; and Bz-Val-Gly-Arg-AMC. In some embodiments the substrate includes the amino acid sequence as one of these substrates but a different blocking moiety and or label.

The terms "chymotrypsin-like substrate" and "chymotryptic substrate" are used interchangeably and meant to refer to substrates which can be spontaneously processed by the chymotrypsin-like protease which is also referred to as chymotryptic protease. Examples of amino acids recognized by chymotrypsin-like protease, i.e. B amino acids, include the hydrophobic amino acids Tryptophan; Tyrosine; Phenylalanine; Methionine; Leucine; and Isoleucine. Examples of chymotrypsin-like substrates include Suc-Arg-Pro-Phe-His-Leu-Leu-Val-Tyr-AMC (SEQ ID NO:1); Z-Gly-Gly-Leu-βNA; Z-Gly-Gly-Leu-AMC; Suc-Leu-Leu-Val-Tyr-Luciferin (SEQ ID NO:2); and Suc-Leu-Tyr-AMC. In some embodiments, the substrate includes the amino acid sequence as one of these substrates but a different blocking moiety and or label.

As used herein, the terms "caspase-like substrate" and "post-acidic protease substrate" are used interchangeably and meant to refer to substrates which can be spontaneously processed by the caspase-like protease which is also referred to as post-acidic protease. Examples of amino acids recognized by caspase-like protease, i.e. C amino acids, include the

acidic amino acids Glutamic acid and Aspartic acid. Examples of caspase-like substrates include Ac-Gly-Pro-Leu-Asp-AMC (SEQ ID NO:3); Z-Leu-Leu-Glu-AMC; Z-Leu-Leu-Glu- β NA; and Ac-nLeu-Pro-nLeu-Asp-AMC (SEQ ID NO:4). In some embodiments the substrate comprises the amino acid sequence as one of these substrates but a different blocking moiety and or label.

The hydrolysis of test substrates by chymotryptic, tryptic and post-acidic proteases is well-described in the literature. These substrates are typically small peptide derivatives that are linked to a fluorogenic reagent that upon release by cleavage by a proteasome protease can be excited by near-UV light to generate a highly sensitive and specific fluorescent signal. The structure, sequence, hydrophobicity and other biophysical properties of these synthetic substrates have been described, and the compounds that are commercially available represent versions that can be generated in bulk and yield good signal. For example, Sato, et al. ((1991) *Eye Res.* 10:485-489) refer to the use of labeled diisopropyl fluorophosphates to measure chymotrypsin-like activity. The degradation of beta-galactosidase-based substrates can be monitored using labeled proteins, and by measuring enzymatic activity using ONPG (o-Nitrophenyl-beta-galactopyranoside) or CPRG (chlorophenol red-beta-D-galactopyranoside). A plating and chromogenic assay can also be performed using IPTG (isopropyl beta-D-thiogalactopyranoside) and X-gal (5-bromo-4-chloro-3-indolyl-beta-D-galactopyranoside). Other enzymes have also been developed into proteasome substrates (including glucuronidase, DHFR, GST and GFP). Moreover, Bachmair & Varshaysky ((1989) *Cell* 56:1019-1032) report that the degradation of DHFR and beta-galactosidase-type substrates show a loss of signal, in the presence of productive degradation by the proteasome. In contrast, degradation of fluorogenic peptide substrates yields a time-dependent increase in fluorescence signal, as the substrate is hydrolyzed by the proteasome.

In carrying out a method of the invention, some embodiments provide that a test sample is added to a container such as a cuvette or test tube. Generally, 0.5-2 ml, typically 1 ml samples are tested. In some embodiments, the container is preloaded with substrate. In some embodiments, the container is preloaded with substrate that is dried and adhered to an inner surface of the container. In other embodiments, the container has a cap with a reservoir that includes substrate. After adding the milk, the cap is used to close the container upon depressing it, the substrate is displaced from the reservoir into the container, typically by rupturing the reservoir. In some embodiments, the substrate is provided in a container such as a dropper or metered dispensers and the substrate is added to the container. The test sample may be mixed and maintained for a period of time sufficient to allow detection of an amount of detectable label that corresponds to the assessment standard being used. Generally, the time of the reaction is 30 seconds to about 5 minutes. After sufficient time has elapsed, if the detectable label is a fluorescent label, the container may be inserted in the fluorometer or luminometer, and the level of fluorescence or luminescence detected. After sufficient time has elapsed, if the detectable label is a luminescent label, the light emitted from the container may be measured and the level of luminescence detected. After sufficient time has elapsed, if the detectable label is a colorimetric label, the container may be inserted in the colorimeter and the level of light of a predetermined wavelength is detected or, if the change in color can be detected visually in the presence of a level of proteasomes indicative of some level of infection, the visual inspection of the container may be undertaken to

determine the results. In each case, the results may be compared to standards known to correspond to one or more levels of infection.

In other embodiments of the invention, a test sample is contacted with a solid surface, such as a stick of plastic or paper. In accordance with this embodiment, the solid surface can be preloaded with substrate such that contacting the test sample with the solid surface places the test sample in contact with the substrate disposed thereon. Alternatively, for example, substrate is contacted with the solid surface after or with the test sample so that the sample is mixed with the substrate. The solid surface with the test sample is maintained for a specified period of time sufficient to allow enzyme present in the sample to process the substrate and produce a detectable label that manifests itself as a color change on the solid surface. The color of the solid surface may be compared to a standard color chart that includes the colors for one or more levels of proteasomes corresponding to one or more levels of infection. Alternatively, the amount of substrate on the surface may be measured with sufficient precision such that when contacted for a specified period of time with a sample containing proteasomes above a threshold amount that corresponds to a level of infection, the solid surface changes color such that it can be visually detected. That is, the amount of reagent disposed on a test strip is calibrated so that a detectable reaction only occurs if the amount of enzyme present is greater than a threshold level. Thus, a test strip is contacted with a milk sample for a specified time and if it undergoes a detectable reaction in that time period, such as changing color, the assay indicates protease levels above a known threshold. For example, the test strip may be manufactured so that it will only change color after a specified time if the protease levels are consistent with a pre-clinical mastitis level, or clinical mastitis level.

ATPase Assays. The intact 26S proteasome contains two 19S regulatory particles. Each 19S particle contains a ring of six ATPases. Therefore, an intact 26S proteasome will contain 12 ATP hydrolyzing enzymes. In this respect, the term "ATPase subunit" is meant to refer to proteasome subunits which can hydrolyze ATP. For example, DeMartino, et al. ((1994) *J. Biol. Chem.* 269:20878-20884) report that PA700, an ATP-dependent activator of the 20S proteasome, is an ATPase containing multiple members of a nucleotide-binding protein family.

Purified proteasomes have robust ATPase activity that can be measured by a broad range of assays that are well-known and routinely performed by those skilled in the art. A luciferase-based ATPase activity is one of the most sensitive. In some embodiments, the assay determines ATP hydrolyzing activities present in raw milk. In some embodiments, the assay includes first isolating proteasomes from a sample and then measuring proteasome-specific ATPase activity. Proteasome isolation may be accomplished, for example, by the method that is disclosed in U.S. Pat. No. 6,294,363, which is incorporated herein by reference. Typical detection methods include a luciferase/luciferin-based approach which generates a robust luminescent signal of high specificity, and very broad dynamic range (linearity over 5-orders of magnitude) however, other systems using different types of detectable signals may also be routine performed. These methods provide another way to monitor proteasome abundance and activity.

De-Ubiquitization Assays. Ubiquitination, the conjugation of proteins to ubiquitin that occurs in a number of cellular processes including endocytosis, DNA repair and degradation by the 26S proteasome is reversible as a number of deubiquitinating enzymes mediate the disassembly of ubiqu-

uitin-protein conjugates. Some deubiquitinating enzymes are associated with the 26S proteasome contributing to and regulating the particle's activity. At least three different deubiquitinating enzymes have been detected in proteasomes.

For example, Stone, et al. ((2004) *J. Mol. Biol.* 344(3):697-706) refer to Uch2/Uch37 as the major deubiquitinating enzyme associated with the 26S proteasome in fission yeast. Fission yeast Uch2 and Ubp6, two proteasome associated deubiquitinating enzymes is reported to be characterized. The human orthologues of these enzymes are known as Uch37 and Usp14, respectively. The subunit Uch2/Uch37 is reported to be the major deubiquitinating enzyme associated with the fission yeast 26S proteasome while the activity of Ubp6 appears to play a more regulatory and/or structural role involving the proteasome subunits Mts1/Rpn9, Mts2/Rpt2 and Mts3/Rpn12. Ubp6 is reported to become essential when activity of these subunits is compromised by conditional mutations.

Proteasome activity can be measured by monitoring associated de-ubiquitinating activity. The vast majority of substrates that are degraded by the proteasome are attached to a chain of ubiquitins. However, these ubiquitins are not degraded along with the substrate, but are released, recycled and used again to target additional proteins to the proteasome. Significantly, the de-ubiquitination of the substrate is required for successful degradation.

Deubiquitinating activity can be measured using well-known routine assays and commercially available fluorogenic or luminescent substrates. In this respect, the term "de-ubiquitinating substrate" is meant to refer to substrates which can be processed by the proteasome de-ubiquitinating enzyme. The method to measure proteasome-associated deubiquitination involves the addition of a substrate such as Ubiquitin-AMC, Ubiquitin-Luciferin, Arg-Gly-Gly-AMC, Arg-Leu-Arg-Gly-Gly-AMC (SEQ ID NO:10), Arg-Leu-Arg-Gly-Gly-Luciferin (SEQ ID NO:10), to other peptide derivatives, to a reaction that contains the de-ubiquitinating activity. Cleavage of the label from the ubiquitin, or from the peptide (e.g., Arg-Gly-Gly-AMC) generates a highly specific signal that can be readily detected with a fluorometer or luminometer. Therefore, the key aspect is that measurement of de-ubiquitinating activity of the proteasome (irrespective of the substrate used), provides an alternate way to measure the level of proteasome and proteasome activity.

Immunoassays. A simple way to gauge the level of the proteasome is by using immunologic methods. Both monoclonal and polyclonal antibodies are available to all subunits of the proteasome. Antibodies against human proteasome subunits can cross-react with the bovine counterparts. The intact 26S proteasome contains approximately 32 subunits, while the immunoproteasome contains approximately 16 subunits (e.g., LMP2, LMP7, and MECL1/LMP10), as well as the proteasome activator, PA28. For example, Kopp, et al. ((1997) *PNAS* 94:2939-2944) refer to subunit arrangement in the human 20S proteasome and report that in human 20S proteasomes two copies of each of seven different α -type and seven different β -type subunits are assembled to form a stack of four seven-membered rings, giving the general structure $\alpha 1-7$, $\beta 1-7$, $\beta 1-7$, $\alpha 1-7$. By means of immunoelectron microscopy and chemical crosslinking of neighboring subunits, the positions of the individual subunits in the proteasome were determined. The topography shows that for the trypsin-like, the chymotrypsin-like, and the post-glutamyl cleaving activities, the pairs of β -type subunits, which are thought to form active sites, are nearest neighbors.

Tanaka & Tsurumi ((1997) *Mol. Biol. Reports* 24:(1-2)3-11) refer to the subunits and functions of the 26S proteasome

and report that the 26S proteasome is an eukaryotic ATP-dependent, dumbbell-shaped protease complex with a molecular mass of approximately 2000 kDa. It is composed of a central 20S proteasome, functioning as a catalytic machine, and two large V-shaped terminal modules, having possible regulatory roles, composed of multiple subunits of 25-110 kDa attached to the central portion in opposite orientations. The regulatory subunits are classified into two subgroups, a subgroup of at least 6 ATPases that constitute a unique multi-gene family encoding homologous polypeptides conserved during evolution and a subgroup of approximately 15 non-ATPase subunits, most of which are structurally unrelated to each other.

Coret, et al. ((1994) *Biochemistry* 33:12229-12237) refer to PRES and PRE6, as genes encoding 20S proteasome subunits from yeast and report that the 20S proteasome of eukaryotes is an abundant multicatalytic/multifunctional proteinase complex composed of an array of nonidentical subunits which are encoded by α - or O-type members of the proteasomal gene family. In budding yeast, 14 subunits had been detected but only 12 proteasomal genes had been cloned. The authors cloned two additional proteasomal genes, PRES and PRE6, which both encode essential α -type subunits. Sequence comparison of all known eukaryotic proteasomal proteins show the presence of a total of 14 subgroups, which can be divided into seven α - and seven O-type groups. Including the Pre5 and Pre6 proteins, every subgroup contains a single yeast member.

In accordance with the instant invention, the level or amount any subunit, associated protein or activator of the proteasome or immunoproteasome can be measured to determine whether an animal has mastitis. One or more of these proteins can be measured using antibodies that are purchased or generated by methods routinely used in the art. Methods of immuno-detection include ELISA, immunoblotting, and antibody-based interference assays. Antibodies conjugated to biotin, magnetic beads, or enzymes (such as alkaline phosphatase) represent other ways to monitor the levels of proteasome subunits.

Diagnostic marker proteins in a sample of raw milk can be detected via binding assays, wherein a binding moiety which specifically recognizes the marker protein (for instance an antibody or naturally occurring binding partner), is introduced into a sample suspected of containing the marker protein. In such an assay, the binding partner is generally labeled as, for example, with a radioisotopic or fluorescent marker. Labeled antibodies can be used in a similar manner in order to isolate selected marker proteins.

Using the instant marker proteins or antibodies, the skilled artisan can use any one of a variety of detection methods for detecting mastitis. The methods typically employ the steps of detecting, by some means, the level of one or more Ub/proteasome pathway marker protein in a sample and comparing said level to that of the marker protein in a control sample to determine whether there is a detectable increase (e.g., 1.5-fold or more) in the level of the marker protein. In general, the test sample can be obtained from young healthy cows, and confirmed independently using SCC analysis.

In a protein-based assay, the marker protein in a sample is detected, for example, by combining the marker protein with an antibody-based binding moiety capable of specifically binding the marker protein. An antibody-based binding moiety of the present invention is intended to include an antibody, antibody fragment or antibody derivative. Binding proteins can also be designed which have enhanced affinity for a target protein. Optionally, the binding moiety can be linked with a detectable label, such as an enzymatic, fluorescent, radioac-

tive, phosphorescent or colored particle label. The labeled complex is detected, e.g., visually or with the aid of a spectrophotometer or other detector.

A Ub/proteasome pathway or ancillary marker protein can also be detected using any of a wide range of immunoassay techniques with qualitative or quantitative results. For example, the skilled artisan can employ the sandwich immunoassay format to detect mastitis in a milk sample. Alternatively, the skilled artisan can use conventional immunohistochemical procedures for detecting the presence of the proteasome or ancillary protein using one or more labeled binding moieties. It is contemplated that either an absolute, semi-quantitative, or relative level of protein expression can be detected using the immunoassays disclosed herein.

In a sandwich immunoassay, two antibodies capable of binding the marker protein generally is used, e.g., one immobilized onto a solid support and one free in solution and labeled with a detectable chemical compound. Examples of chemical labels that are useful for the second antibody include radioisotopes, fluorescent compounds, and enzymes or other molecules that generate colored or electrochemically active products when exposed to a reactant or enzyme substrate. When a sample containing the marker protein is placed in this system, the marker protein binds to both the immobilized antibody and the labeled antibody, to form a "sandwich" immune complex on the support's surface. The complexed protein is detected by washing away non-bound sample components and excess labeled antibody, and measuring the amount of labeled antibody complexed to protein on the support's surface. Alternatively, the antibody free in solution can be detected by a third antibody labeled with a detectable moiety which binds the free antibody or, for example, a hapten coupled thereto.

Both the sandwich immunoassay and tissue immunohistochemical procedures are highly specific and very sensitive, provided that labels with good limits of detection are used. A detailed review of immunological assay design, theory and protocols can be found in numerous texts in the art, including *Practical Immunology*, Butt, ed. (1984) Marcel Dekker, New York; and *Antibodies, A Laboratory Approach*, Harlow, et al., eds. (1988) Cold Spring Harbor Laboratory.

In general, immunoassay design considerations include preparation of antibodies (e.g., monoclonal or polyclonal antibodies), antibody fragments, or antibody derivatives having sufficiently high binding specificity for the target protein to form a complex that can be distinguished reliably from products of nonspecific interactions. As used herein, the term "antibody" is understood to mean binding proteins, for example, antibodies or other proteins comprising an immunoglobulin variable region-like binding domain, having the appropriate binding affinities and specificities for the target protein. Higher antibody binding specificity will permit detection of lower amounts of the target protein. As used herein, the terms "specific binding" or "specifically binds" are understood to mean that the binding moiety, for example, an antibody, has a binding affinity for the target protein of greater than 10^5 M^{-1} or greater than about 10^7 M^{-1} .

Antibody binding domains also can be produced biosynthetically and the amino acid sequence of the binding domain manipulated to enhance binding affinity with a preferred epitope on the target protein. Specific antibody methodologies are well-understood and described in the literature. A more detailed description of their preparation can be found, for example, in *Practical Immunology* (1984) supra.

Chimeric antibodies are also contemplated. Techniques developed for the production of chimeric antibodies (Morrison, et al. (1984) *Proc. Natl. Acad. Sci. USA* 81:6851-6855;

Neuberger, et al. (1984) *Nature* 312:604-608; Takeda, et al. (1985) *Nature* 314:452-454) by splicing the genes from a mouse antibody molecule of appropriate antigen specificity together with genes from a human antibody molecule of appropriate biological activity can be used. A chimeric antibody is a molecule in which different portions are derived from different animal species, such as those having a variable region derived from a murine monoclonal antibody and a human immunoglobulin constant region.

Antibodies can also be modified, e.g., to produce a number of well-characterized fragments generated by digestion with various peptidases. For example, pepsin digestion of an antibody produces F(ab)'_2 . The F(ab)'_2 can further be reduced under mild conditions to break the disulfide linkage in the hinge region, thereby converting the F(ab)'_2 dimer into an Fab' monomer. The Fab' monomer is essentially a Fab with part of the hinge region (see, *Fundamental Immunology*, Third Edition (1993) Paul, ed., Raven Press, NY). While various antibody fragments are defined in terms of the digestion of an intact antibody, one of skill will appreciate that such fragments can be synthesized de novo either chemically or by utilizing recombinant DNA methodology. Accordingly, the term antibody fragment also includes fragments either produced by the modification of whole antibodies or those synthesized de novo using recombinant DNA methodologies. Thus, an antibody fragment includes, but is not limited to, single chain antibodies, Fab fragments, F(ab)'_2 fragments, diabodies (Holliger, et al. (1993) *Proc. Natl. Acad. Sci. USA* 90:6444; Poljak (1994) *Structure* 2:1121-1123), fragments produced by a Fab expression library (Huse, et al. (1989) *Science* 246:1275-1281), and epitope-binding fragments of any of the above.

Antibody derivatives such as peptide aptamers, which are selected for specifically binding to a proteasome subunit or ancillary protein in mastitis, are also provided in the instant invention. Peptide aptamers can be rationally designed or screened for in a library of aptamers (e.g., provided by Aptamomics SA, Lyon, France). In general, peptide aptamers are synthetic recognition molecules whose design is based on the structure of antibodies. Peptide aptamers consist of a variable peptide loop attached at both ends to a protein scaffold. This double structural constraint greatly increases the binding affinity of the peptide aptamer to levels comparable to that of an antibody (nanomolar range).

Binding moieties to the instant protein markers are used in the diagnostic assays disclosed herein as well as in kits to detect the level of the proteins in a milk sample. For example, a kit of the invention can include one or more binding moieties (e.g., antibodies, antibody fragments, or antibody derivatives) which bind specifically to one or more Ub/proteasome pathway or ancillary proteins and which permit the relative level and/or specific concentration of the Ub/proteasome pathway or ancillary proteins to be detected and/or quantitated in a milk sample.

Suitable kits for detecting Ub/proteasome pathway or ancillary proteins are contemplated to include, e.g., a receptacle or other means for capturing a sample to be evaluated, and means for detecting the presence and/or quantity in the sample of one or more of the Ub/proteasome pathway or ancillary proteins described herein. As used herein, "means for detecting" in one embodiment includes one or more antibodies specific for these proteins and means for detecting the binding of the antibodies to these proteins by, e.g., a standard sandwich immunoassay as described herein. Where the presence of a protein within a cell is to be detected, e.g., as from a milk sample, the kit also includes a means for separating the proteasomes from fat globules and casein present in the milk.

The kit can further contain written information, such as procedures for carrying out the method of the present invention or analytical information, such as representative values for proteasome activity as a function of SCC levels, as well as with low and high expression levels of a specific reference protein. Such a kit is developed, validated and commercially available (see U.S. Pat. No. 6,294,363).

Antibodies against ubiquitin and its derivatives also provide a method for monitoring the abundance of this pathway, since the majority of proteasome-substrates are attached to multi-ubiquitin chains. A kit to achieve this is developed, validated and commercially available (see US Application No. 2005/0287608). An ubiquitin binding matrix may be used to collect ubiquitinated proteins from raw milk. The level of such proteins may be measured and compared to the range found in milk from uninfected individuals.

Nucleic Acid Based Assays. In other embodiments, the occurrence of mastitis can also be determined by detecting, in a milk sample, one or more nucleic acid molecules encoding one or more Ub/proteasome pathway or ancillary proteins. Using methods well-known to those of ordinary skill in the art, one or more oligonucleotide probes are designed to specifically hybridize with a nucleic acid molecule encoding a Ub/proteasome pathway or ancillary protein, e.g., nucleic acid molecules disclosed in the GENBANK Accession Nos. disclosed herein.

The expression of proteasome subunits and proteasome-associated factors can be readily determined, in real time, using quantitative PCR. The sequence of the human genome is available, and the design of effective PCR oligonucleotides can be generated using both public and proprietary programming software. (Bovine-specific RNA sequences can be based on homology to other mammalian species, and further refined as nucleic acid sequences become available). The 26S proteasome contains approximately 32 distinct subunits, whose sequence is highly conserved across evolution. The immunoproteasome contains fewer than 32, but does contain approximately 5 novel subunits. Additionally, hundreds of regulatory factors form transient interactions with the proteasome. Antibodies against human, mouse, rat, dog, worm, fly, yeast and other species can be tested for cross-reactivity against the bovine proteins. In tests conducted thus far, all the human specific antibodies examined have reacted against the bovine proteins.

A target nucleic acid molecule encoding an Ub/proteasome pathway or ancillary protein marker can be detected using a labeled binding moiety capable of specifically binding the target nucleic acid. The binding moiety can be, for example, a protein, a nucleic acid or a peptide nucleic acid. Additionally, a target nucleic acid, such as an mRNA encoding a Ub/proteasome pathway or ancillary protein, can be detected by conducting, for example, a northern blot analysis using labeled oligonucleotides, e.g., nucleic acid fragments complementary to and capable of hybridizing specifically with at least a portion of a target nucleic acid.

More specifically, gene probes composed of complementary RNA or, preferably, DNA to the Ub/proteasome pathway or ancillary protein nucleotide sequences or mRNA sequences encoding Ub/proteasome pathway or ancillary proteins can be produced using established recombinant techniques or oligonucleotide synthesis. The probes hybridize with complementary nucleic acid sequences presented in the test specimen, and provide exquisite specificity. A short, well-defined probe, coding for a single unique sequence is most precise and preferred. Larger probes are generally less specific. While an oligonucleotide of any length can hybridize to an mRNA transcript, oligonucleotides typically within the

range of 8-100 nucleotides, preferably within the range of 15-50 nucleotides, are envisioned to be most useful in standard hybridization assays. Choices of probe length and sequence allow one to choose the degree of specificity desired. Hybridization is generally carried out at from 50° C. to 65° C. in a high salt buffer solution, formamide or other agents to set the degree of complementarity required. Furthermore, the state of the art is such that probes can be manufactured to recognize essentially any DNA or RNA sequence. For additional methodologies, see, for example, *Guide to Molecular Techniques*, Berger, et al. (1987) Methods of Enzymology, Vol. 152. A wide variety of different labels coupled to the probes or antibodies can be employed in the instant assays. The labeled reagents can be provided in solution or coupled to an insoluble support, depending on the design of the assay. The various conjugates can be joined covalently or non-covalently, directly or indirectly. When bonded covalently, the particular linkage group will depend upon the nature of the two moieties to be bonded. A large number of linking groups and methods for linking are taught in the literature. Broadly, the labels can be divided into the following categories: chromogens; catalyzed reactions; chemiluminescence; radioactive labels; and colloidal-sized colored particles. The chromogens include compounds which absorb light in a distinctive range so that a color is observed, or emit light when irradiated with light of a particular wavelength or wavelength range, e.g., fluorescers. Both enzymatic and nonenzymatic catalysts can be employed. In choosing a proteasome substrate, there will be many considerations including the stability of the substrate. A chemiluminescent label involves a compound that becomes electronically excited by a chemical reaction and emits light that serves as a detectable signal or donates energy to a fluorescent acceptor. Radioactive labels include various radioisotopes found in common use such as the unstable forms of hydrogen, iodine, phosphorus, sulphur, or the like. Colloidal-sized colored particles involve material such as colloidal gold that, in aggregate, form a visually detectable distinctive spot corresponding to the site of a substance to be detected. Additional information on labeling technology is disclosed, for example, in U.S. Pat. No. 4,366,241.

Once the level or activity of Ub/proteasome pathway or ancillary protein or nucleic acid encoding such protein is detected or measured in the test milk sample, it is compared to the level or activity of Ub/proteasome pathway or ancillary protein or nucleic acid encoding such protein in one or more controls in order to determine whether the subject from which the sample was obtained has mastitis.

As exemplified herein, a control can be a milk sample obtained from a healthy cow. By using one or more control samples (e.g., in a panel), the skilled technician can compare the level of proteasome activity, or abundance of ancillary proteins in an immunological or immunohistochemical assay, or absolute level of expression in an ELISA for a semi-quantitative or quantitative result. Although the present methodology emphasizes the characterization of proteasome activity as a key measure of infection, measuring the abundance of the proteasome and ancillary components, and/or the levels of specific mRNAs or DNA, also serves as useful indicators of mastitis.

Interaction with Organic Copper Complexes. The abundance of the proteasome can be determined by examining its interaction with organic copper complexes (including NCI-109268 and bis-8-hydroxyquinoline copper(II) [Cu(8-OHQ)₂], and 5,7-dichloro-8-hydroxyquinoline-copper(II)). These reagents inhibit the chymotryptic activity of the proteasome, and generate a green stain upon interaction with the

proteasome. The ability of specific proteasome subunits and/or regulatory factors to bind copper can be used in the instant detection system to measure proteasome levels.

A variety of copper complexes can bind and inhibit the proteasome. Furthermore, the interaction results in a green stain that can be detected. Copper-binding compounds have been reported as proteasome inhibitors and apoptosis inducers in human cancer. Several copper-binding compounds have been reported to spontaneously complex with copper and form active proteasome inhibitors and apoptosis inducers. For example, compounds in the quinoline and dithiocarbamate families may bind with copper and inhibit the proteasome activity. Compounds, such as clioquinol and pyrrolidinedithiocarbamate as examples, form complexes with copper and bind to proteasomes.

Detection of Proteasome Regulatory Factors. The proteasome can be rapidly purified, for example, as disclosed above. For example, U.S. Pat. No. 6,294,363 provides for one-step, rapid purification of proteasomes. The presence of key regulatory factors can be established using immunologic methods, such as antibodies. The presence of these factors in raw milk provides a key indicator for the presence of proteasomes, and therefore a gauge of the level of inflammatory cells in the milk. As noted above, this provides a way to assess the level of infection, which is strongly related to the level of pathogen/infection.

Detection of Proteasome Bound Factors. An important, and additional application of the instant methods relates to the fact that some proteasome-bound factors have well-described biochemical properties. It has been shown that ubiquitin-conjugating enzymes (Ubc4, Ubc5), and translation elongation factor (eEF1A), can be detected in association with the proteasome. In addition, the association of ubiquitin-E3 ligases (Ubr1, Scf), de-glycosylases (Png1) and kinases (Cdc2) with the proteasome has been described. Proteasomes have also been reported to have RNase activity. Notably, all these factors have well-described biochemical properties that can be readily measured. Therefore, measuring these and other biochemical activities in purified proteasomes provides a method for detecting the levels of proteasomes, and the likelihood of mastitis.

For example, Gautier-Bert, et al. ((2003) *Mol. Biol. Rep.* 30:1-7) refer to and report partially reconstituted 20S proteasome/RNA complexes using oligonucleotides corresponding to ARE (adenosine- and uridine-rich element) (AUUUA)₄ (SEQ ID NO:5) and HIV-TAR (human immunodeficiency virus-Tat transactivation response element), a stem-loop structure in the 5' UTR (untranslated region) of HIV-mRNAs. RNAs which associate with proteasomes are degraded by proteasomal endonuclease activity. The formation of these 20S proteasome/RNA substrate complexes is rather specific since 20S proteasomes do not interfere with truncated TAR that is not cleaved by proteasomal endonuclease. In addition, affinity of proteasomes for (AUUUA)₄ (SEQ ID NO:5) is much stronger than it is for HIV-TAR.

In addition, Jarrousse, et al. ((1999) *J. Biol. Chem.* 274: 5925-5930) refer to possible involvement of proteasomes (Prosome) in mRNA decay and report on a cellular target for proteasomal endonuclease activity, indicating that 20S proteasomes interact with the 3'-untranslated region of certain cytoplasmic mRNAs in vivo, and 20S proteasomes isolated from Friend leukemia virus-infected mouse spleen cells associate with an mRNA fragment showing great homology to the 3'-untranslated region of tumor necrosis factor β (TNF β) mRNA that contains AUUUA sequences. Destabilization of oligoribonucleotides corresponding to the 3'-untranslated region of TNF β by 20S proteasomes and the creation a spe-

cific cleavage pattern are reported. The cleavage reaction is accelerated with increasing number of AUUUA motifs, and major cleavage sites are localized at the 5' side of the A residues.

Detectably labeled RNA substrates can be used in assays to detect proteasome RNase activity in a milk sample. The level of RNase activity relative to the level of RNase activity in milk from an uninfected animal and/or infected animal indicates whether the animal is infected or not.

Proteasome associated Peptide N-glycanase (PNGase; glycoamidase; N-glycanase) activity can also be measured as an indication of proteasome levels. Png1 is a deglycosylating enzyme that removes asparagine-linked (N-linked) glycans from glycoproteins/glycopeptides that have been targeted for degradation by the proteasome. The interaction between Png1 and the proteasome-docking (shuttle) factor Rad23 is significant, because this interaction promotes the localization of PNGase activity with the proteasome. Suzuki, et al. ((2002) *FASEB J.* 16:635-641) refer to the occurrence, primary structure, and potential functions of cytoplasmic peptide:N-glycanase (PNGase) in eukaryotic cells. Suzuki & Lennarz ((2003) *Biochem. Biophys. Res. Commun.* 302:1-5) hypothesize that a glycoprotein-degradation complex is formed by protein-protein interaction involves cytoplasmic peptide:N-glycanase.

Assays measuring removal of asparagine-linked (N-linked) glycans from glycoprotein/glycopeptides substrates by Png1 are useful in measuring proteasome levels in a sample. In such assays, the substrate includes a detectable label that is either detectable before processing by Png1 but not after, or not detectable before processing by Png1 but detectable after the enzyme reaction.

Proteasome-associated lipase activity may also be used as an enzyme-based assay which correlates to proteasome levels. In this respect, Ohsak, et al. ((2006) *MBC* 17:2674-2683) refer to cytoplasmic lipid droplets as being sites of convergence of proteasomal and autophagic degradation of Apolipoprotein B. Lipid esters stored in cytoplasmic lipid droplets (CLDs) of hepatocytes are reported to be used to synthesize very low-density lipoproteins (VLDLs), into which apolipoprotein B (ApoB) is integrated cotranslationally. Using Huh7 cells derived from human hepatoma and competent for VLDL secretion, ApoB was found to be highly concentrated around CLDs to make "ApoB-crescents." ApoB-crescents were reportedly seen in <10% of Huh7 cells under normal conditions, but the ratio increased to nearly 50% after 12 hours of proteasomal inhibition by N-acetyl-L-leucyl-L-leucyl-L-norleucinal. Electron microscopy reportedly showed ApoB to be localized to a cluster of electron-lucent particles 50-100 nm in diameter adhering to CLDs. ApoB, proteasome subunits, and ubiquitinated proteins were detected in the CLD fraction, and this ApoB was ubiquitinated. Proteasome inhibition reportedly caused increases in autophagic vacuoles and ApoB in lysosomes in which ApoB-crescents began to decrease after 12-24 hours of proteasomal inhibition, but the decrease was blocked by an autophagy inhibitor, 3-methyladenine inhibition of autophagy alone reportedly caused an increase in ApoB-crescents. Proteasomal and autophagy/lysosomal degradation of ApoB may occur around CLDs and that the CLD surface functions as a unique platform for convergence of the two pathways.

Accordingly, detectably labeled lipase substrates can be used to determine proteasome-associated lipase activity as an indication of proteasome levels in a sample. The reagents referred to herein may be adapted to detectably label lipase substrates. Enzyme activity can be measured and used as an indicator of proteasome levels.

The invention is described in greater detail by the following non-limiting examples.

EXAMPLE 1

Application of Proteasome Assays to Detecting Mastitis

The methods and systems provided are particularly useful for the early detection of mastitis and monitoring or treatment for various milk producing animals such as the dairy cow. However, the methods are broadly applicable to other organisms, including human, and to other conditions such as malignant growth and pathology. The method involves detecting the abundance and activity of the ubiquitin/proteasome pathway in a sample of unprocessed (raw) milk, wherein an increase in proteasome activity in the sample, as compared to a control, is indicative of mastitis. The invention also includes detecting the level of ancillary proteins of the ubiquitin/proteasome pathway and of the immunoproteasome. In a different embodiment of this invention the mRNA expression of components of the ubiquitin/proteasome pathway are measured using variations of polymerase chain reaction-based amplification. Oligonucleotide-based detection of released nuclear DNA from somatic cells is also envisioned. There has been no prior description of a measurement of the activity of the ubiquitin/proteasome pathway in milk or utility of such an approach for detecting mastitis.

A kit that will permit early detection, routine monitoring of milk quality, and surveillance of animals that are recovering following illness is also embraced by this invention. The ability to monitor milk quality and animal health can have a direct positive effect on animal welfare and husbandry. Furthermore, a diagnostic kit developed from the invention will be applied on-site at milking facilities. While this technology and methodology can monitor milk quality and animal welfare, its applicability is not restricted to the dairy industry. The invention is highly novel, and broadly applicable to all mammals that are of commercial interest and personal value. For instance, other farm animals (including goat, sheep and horse), and animals of non-commercial value (pets) can also suffer from mastitis. Mastitis is a medical concern in the lactating woman, and the invention can be readily adapted to the nursing mother. The applicability of this invention was verified for monitoring the quality of dairy milk, and following the drug response of infected dairy cows. The invention provides a mechanism to monitor efficacy of drug regimen, and recovery of the animal.

Mastitis is an inflammatory response, which can cause the release of somatic cells into the milk, possibly through lesions in the lining of the udder. Because systemic inflammation involves activation of white blood cells, it was envisioned that a significant fraction of the somatic cells in the milk represent cow white blood cells. In earlier studies proteasome activity had been detected in blood cells. However, detection of white blood cells or proteasome activity in raw whole milk has not been envisaged or demonstrated by direct or indirect experiments. Also, prior to the instant invention, it was not clear whether the milk could be used in its native raw state or if it needed to be purified to remove other interfering components so that a reliable and accurate determination of the proteasome and related assays could be carried out. It was recognized that milk contains high levels of lipid micelles, and proteins including casein. High sensitive enzymatic assays for analyzing raw milk have not been described, since the turbidity caused by scattering of light by the colloidal particles in the milk emulsion precludes most biochemical mea-

surements. Therefore, it was determined whether proteasome activity could be detectable in bulk milk. The experimental findings herein demonstrate that proteasome activity can be measured in whole raw milk, without a prior need for purifying somatic cells.

In contrast, performing a somatic cell count (SCC) requires specialized instruments, and cannot be performed by straightforward microscopy, because turbidity and light scattering by the milk suspension interferes with the visual inspection of the somatic cells. Furthermore, large aggregates of casein and lipid vesicles prevent clear visualization of the somatic cells. Consequently, the SCC is determined by external laboratories and the dairy farm is not informed of the results for several weeks or months.

This delay provides no benefit to the dairy farmer for monitoring, identifying, quarantining and restoring an infected animal to the milk line. Moreover, the presence of a single infected animal greatly increases the probability of cross-contamination and infection of other animals. Note that the same vacuum tubes are used for collecting milk from many cows, and inadequate treatment with disinfectant can contaminate the next cow that is tethered to the lines.

In the experiments conducted, high levels of a proteasome variant, called the 'Immunoproteasome,' were detected in mastitis-affected milk. This form of the proteasome contains distinct subunits, and is specifically required for the immune response, consistent with the inflammation that accompanies mastitis.

Affinity purification and immunological experiments were also carried out to define the abundance and activity of various proteasome isoforms. It was determined that the higher proteasome activity in mastitis milk was due to increased expression of proteasomes, and proteasome-isoforms. As noted above, high levels of the 'immunoproteasome' were detected. This finding provides a powerful means to monitor the onset, progression and remission of inflammation, using a straightforward antibody-based assay, which will complement the activity measurement.

In total, the detection of proteasome level may be achieved by measuring both proteasome activity and abundance. The 26S proteasome and its component 19S and 20S particles can be detected. The 'immunoproteasome' and the associated PA28/13S complex, and novel 20S catalytic particle can also be the subject of a test assay. Regulatory factors that form transient interactions with the proteasome including, but not restricted to, eEF1A, Hsp70, E2 and E3 enzymes, Sts1, Centrin and the family of UbL/UBA shuttle factors (e.g., Rad23, Dsk2, Ddi1), and multi-ubiquitinated proteins that are degraded by the proteasome can also be used in such assays.

These assays provide measurements for mastitis that are both sensitive and quantitative. Moreover, these assays can be performed in the field and can be provided in a simple kit format. These key advances address the critical deficiencies of the current methods, because the instant invention detects inflammation before physical manifestation of mastitis is observed, and the assay can be performed on-site. Therefore, an early detection method is envisioned that overcomes the deficiencies in the current methods. In dairy farms, milk from a large number of cows is collected in a common reservoir. It is therefore critical to detect infected animals and to remove them from the milk line, before the quality of the milk in the common reservoir has deteriorated. This is not possible with either SCC or the CMT assay. CMT is non-quantitative, and SCC results are provided weeks after sampling. In contrast, the present invention can detect infected milk originating from fewer than 1/100 infected animals, and the results can be provided in minutes. Thus, the presence of a single infected

animal can be initially detected by testing the bulk reservoir. Based on the outcome of the test, the offending animal can be identified, withdrawn and treated. The outstanding sensitivity of the instant assay stands in contrast to the high SCC level that is permitted in unprocessed whole milk (Maximum about 750,000 SCC/ml; typical bulk reservoir averages >200,000 SCC/ml, whereas high quality farms may achieve levels below about 40,000 SCC/ml). Thus, the instant invention provides extraordinary sensitivity, wherein, high proteasome activity in milk, caused by a single infected animal, can be readily detected in the bulk reservoir. Once the affected animal is identified, the invention allows quantitatively monitoring treatment and recovery, and assisting the farmer in returning the cow to the milk line.

While some embodiments embrace detecting the level of Ub/proteasome pathway or ancillary protein, other embodiments embrace detecting the activity of such proteins. As exemplified herein, an increase in Ub/proteasome pathway proteins is correlated with an increase in proteasome activity. Accordingly, proteasome activity, e.g., as determined using a substrate such as Suc-LLVY-Luciferin (SEQ ID NO:2) or detection of multi-ubiquitinated proteins, can also be used for pre-clinical detection of mastitis.

EXAMPLE 2

Proteasome Activity in Raw Milk

Raw milk samples were obtained from a local farm once a week for 16 consecutive weeks. Samples (approximately 30 ml) were collected from the daily first milking (about 5:00 am) and then stored on ice. All samples were collected by 8:30 am, and processed for proteasome activity by 10:30 am. Proteasome activity was determined at 37° C. with the fluorogenic substrate Suc-LLVY-AMC (SEQ ID NO:2), and quantified using a TURNER 7000 fluorometer. Overall protein concentration was highly uniform, and reflected the very high levels of casein and other abundant milk proteins. Therefore, a volume-based assay was most reliable. The results of this analysis are presented in FIG. 1.

In the first set of seven columns of FIG. 1, the level of proteasome activity was measured in triplicate from samples taken from the bulk reservoir (maintained at 10° C.). Milk in this reservoir represented the collective output from approximately 50 cows. Typically, the reservoir contained the output of several days of milking. Note the very low levels of proteasome activity in the bulk reservoir (BULK), and relatively consistent values in seven independent samplings. A specific young healthy female (named Sunshine) was sampled twice, on independent occasions, and low proteasome activity was detected. Another individual cow (Dale) was examined one day after calving and it showed high activity that was restored to lower levels over the next two weeks. It is well known that calving results in high SCC levels in the milk. However, this is a transient phenomenon that can be recapitulated. Two independent cows, suffering from mastitis, were examined.

COW1 had very high levels that required antibiotic treatment. Following a single treatment regimen, proteasome activity was examined and a precipitous drop to near normal levels was detected. However, treatment was insufficient and proteasome activity increased dramatically over the course of the next week. Treatment was restored, and lower proteasome activity was observed. Note that baseline levels remained elevated. It was significant that failure to monitor treatment response in a quantitative manner results in inadequate treatment, premature return to the milk line, degradation of bulk tank quality, and recurrence of the infection. Neither the SCC

nor the CMT assays currently in use can provide these key measurements. In contrast, the present invention permits rapid, real-time quantitative analysis of milk quality and animal health.

In COW2, rapid onset of mastitis, following injury of one teat, required antibiotic treatment. Proteasome activity in this animal was followed over the next two weeks and a dramatic decline was observed as the injury/infection receded and the animal was returned to the milk line. Note that baseline levels were elevated compared to Sunshine, and unaffected bulk reservoir levels.

COW3 was termed a 'chronic offender' by the farmer. This animal was examined over the course of several weeks, and as noted by the dairy farmer, this individual had chronic elevated proteasome activity that fluctuated quite widely. This would represent a highly troublesome animal that would need constant monitoring.

COW4 was under watch by the farmer, as an animal with potential pre-clinical mastitis. As suspected, elevated levels of proteasome activity were detected, which were restored to the normal range without treatment. These two samples (COW3 and COW4) illustrate the significant difficulty of relying on subjective criterion for identifying troublesome animals. The present invention provides rapid and quantitative assessment of milk quality and animal health, and removes intuition and guess-work from the decision.

To determine proteasome levels, raw milk samples were separated in SDS-polyacrylamide gels, and the separated proteins were transferred to nitrocellulose. The filters were treated with antibodies against the proteasome subunits Rpn2 and Rpt1, as well as Ub (ubiquitin). Milk samples from the Bulk Reservoir, and Cow1, Cow2, Cow3 and Cow4 were analyzed. The samples were acquired on the dates indicated (for example; S19=Sep. 16, 2006). Note that low levels of proteasome subunits and ubiquitin were detected in the Bulk Reservoir, consistent with low proteasome activity (see FIG. 2A). In contrast, Cow1 and Cow2 had significantly elevated amounts of both proteasome subunits and high molecular weight multi-Ubiquitinated proteins, consistent with dramatic increase in proteasome activity (FIG. 2A). The levels of proteasome subunits and ubiquitin cross-reacting material were elevated in Cow3 and Cow4, but not to the same degree as Cow1 and Cow2, again in agreement with the activity measurements (FIG. 2A).

To further verify these results, proteasomes were purified from raw milk using a UbL affinity matrix. Highly purified proteasomes were separated in SDS-polyacrylamide gels and examined by immunoblotting. Consistent with the previous panel, higher proteasome levels were detected in Cow1 and Cow2, with a more moderate increase in Cow3 and Cow4, entirely consistent with the activity measurements (FIG. 2B).

In an independent measurement of proteasome abundance, the levels of the Rpt1 proteasome subunit in raw milk were retested on specific dates for a number of candidate animals. As shown in FIG. 3A, a sampling from Oct. 9, 2006, when Cow1 and Cow2 showed dramatically elevated proteasome activity, detected a corresponding elevation in the levels of the Rpt1 proteasome subunit. In contrast, Rpt1 was not detected in Bulk tank, Dale, SunShine, or Cow3 and Cow4. Note that on October 9, both Cow3 and Cow4 had low proteasome activity.

The same immunofilters were reacted with antibodies against the immunoproteasome subunit PA28a. High levels were observed in Cow1 and Cow2 (lanes 5 and 7), consistent with an immune response that occurs during the inflammatory response following infection and injury.

To confirm that intact proteasomes were present in mastitis milk, a 10-fold higher amount of raw milk was applied to UBL matrix to purify proteasomes. Immunoblots were examined and Rpt1 was detected in Cow1 and Cow2 (FIG. 3B). Lower amounts were observed in Cow3, and very low levels were detected in Cow4. In contrast, Rpt1 was not detected in Bulk tank, Dale or SunShine.

A careful assessment of an individual cow, chronically infected with mastitis was followed over the course of approximately 4 weeks. Proteasome activity was compared to the averaged value from the bulk tank, taken at each time point (FIG. 4). Note that the average value was 27 units of proteasome activity. The activity in the infected animal ranged 100-fold, from 21 to 2156. Significantly, the animal responded efficiently to treatment with antibiotic (reduced from 2156 to 21), but significantly higher levels were detected within one week following termination of treatment.

EXAMPLE 3

Assays for Determining Proteasome Activity

To monitor chymotryptic, tryptic and caspase-like activities as an indication of proteasome activity, labeled substrates specific for one or more proteases can be used. To determine proteasome subunit abundance, high-affinity immunologic methods were used. To detect de-ubiquitylation activity, the levels of ubiquitin, multi-ubiquitin, and ubiquitinated substrates can be determined using immunologic methods. Alternatively, the assembly of catalytically active 26S proteasomes, from its component 19S and 20S particles, can be measured. The level of the ‘Immunoproteasome’ and the associated PA28/13S complex, and novel 20S catalytic particle, can be determined using immunologic methods.

EXAMPLE 4

Use of a Fluorogenic Substrate to Determine Proteasome (Chymotryptic) Activity

Raw milk (50 µl) is suspended in 500 µl lysis buffer (50 mM HEPES, pH 7.5, 150 mM NaCl, 5 mM EDTA and 1% TRITON X-100), lysed by sonication, and total protein quantified using the Bradford assay (BIORAD). Protein extracts contain a protease inhibitor cocktail (Roche), to prevent non-proteasomal proteolysis. Protein extracts (20 µg) are characterized in triplicate in a 96-well microtiter plate. Reactions are incubated for 5 minutes at room temperature, in the presence or absence of the proteasome inhibitors epoxomicin and lactacystin. Proteasome activity is determined by examining the hydrolysis of SUC-LLVY-AMC (SEQ ID NO:2) (Boston Biochem), in 25 mM HEPES pH 7.5, 0.5 mM EDTA. Each reaction, containing 40 µM of SUC-LLVY-AMC (SEQ ID NO:2), is incubated for 1 hour at 30° C., and the fluorescence signal quantified over time using a TECAN INFINITE F200 plate reader. Proteasome activity is calculated after subtracting non-specific activity that is insensitive to epoxomicin-sensitive hydrolysis. Steady-state and kinetic measurements are obtained.

EXAMPLE 5

Peptide Substrates

The P4 position from the cleavage site is important for the ability of the proteasome hydrolytic activity to recognize a substrate. This implied that there is a length constraint that

must be met to generate an ideal proteasome substrate. Many different residues can be tolerated at the P4 position, although differences in cleavage efficiency can be detected. Proteasome substrates include the peptide-based substrate Suc-LLVY-AMC (SEQ ID NO:2), and the eight-residue long Suc-RPFHLLVY-AMC (SEQ ID NO:1). The amino-terminus is generally blocked using succinimide (Suc), acetate (Ac), benzoyl (Bz), BOC (tert-butyloxycarbonyl), carboxybenzyl (Z), vinyl and phenyl groups. Other peptide substrates are listed in Table 1.

TABLE 1

Activity	Substrate	SEQ ID NO:
Caspase-like	Ac-nLPnLD	6
Trypsin-like	Ac-RLR	
Caspase-like	Ac-GPLD	7
Trypsin-like	Boc-LRR	
Trypsin-like	Bz-VGR	
Chymotrypsin-like	Suc-RPFHLLVY	8
Chymotrypsin-like	Z-GGL	
Caspase-like	Z-LLE	
Chymotrypsin-like	Suc-LLVY	9

These substrates can be conjugated (e.g., at the C-terminus) with a detectable label including, but not limited to, a fluorogenic label, luminescent label or a chromogenic label.

EXAMPLE 6

Luminescent Assay for Detecting Proteasome Activity

In addition to the commonly used fluorogenic assay using, e.g., AMC, a luminescent assay using the firefly luciferase enzyme is also available using commercially available materials and well-known techniques. Examples of luminescent assays include the reaction set forth in FIG. 5. In this assay, cleavage of LLVY-Luciferin by the proteasome releases Luciferin. In the presence of luciferase, a catalytic reaction, requiring ATP, releases a photon of light, the signal of which is detectable with a hand-held luminometer. As with a fluorogenic assay, this assay for proteasome activity is sensitive, linear, and quantitative; has a wide dynamic range; and has a low signal background.

Protocol for Measuring Proteasome Activity in Raw Milk Using a Luminescent Readout. A sample of milk (0.2-0.5 ml) is placed in a clear UV-light transmissible tube. A defined quantity of the chymotryptic substrate, Suc-Leu-Leu-Val-Tyr-Luciferin (SEQ ID NO:2) is added. A defined quantity of the enzyme luciferase is added to generate a bioluminescent readout. In particular embodiments, a genetically modified *Photuris pennsylvanica* luciferase enzyme (LucPpe2TM) is employed, which has improved thermostability ranging from 22° C. to 60° C., and catalyzes cleavage over a longer period, allowing much more accurate measurements to be obtained (see U.S. Pat. Nos. 6,602,677 and 7,241,584, incorporated herein by reference). In this respect, the assay can be conducted over a broad dynamic range (>5-orders of magnitude), and in a convenient time-frame (1-10 minute duration). Moreover, the use of a genetically modified Luciferase is an improvement over existing technology for using bioluminescence measurements, because the release of light is significantly more controlled, and does not cause the rapid burst in photon release as observed with native bioluminescence generating enzymes.

Cleavage of Suc-LLVY-Luciferin (SEQ ID NO:2) by the proteasome, releases free Luciferin. In a reaction containing

25

Luciferin and ATP (already present in raw milk), Luciferin generates light. The release of light is detected by a luminometer. The reactions are performed at ambient temperature. Experimental evidence shows approximately a 2-fold increase in signal from 15° C.->37° C., within the typical range of dairy farm housing of cows. The resulting signal is highly reproducible, rapid, quantitative, and is a function of proteasome abundance in the raw milk and the availability of free ATP; both are strong indicators of somatic cell levels.

Proteasome Activity in Raw Milk. It has been shown that there is strong correlation between ATP levels and somatic cells, as well as proteasome activity and somatic cells. Somatic cell counts ranging from <20,000/ml to greater than 1x107/ml were examined, and corresponding proteasome activity was detected. At low SCC levels, luminescent signal is detected within 10 minutes. However, at high SCC levels (>1x106/ml), signal can be detected in less than 30 seconds.

SCC values in the raw milk samples were obtained at a remote testing facility. The same milk samples were used to generate both SCC and proteasome activity measurements. Samples representative of pre-clinical mastitis showed activity in 1-3 minutes. SCC measurements in these samples ranged from 200,000-400,000/ml.

Kit for Determining Proteasome Activity in Raw Milk. The application of a single-use disposable measuring device was validated. An applicator stick deposits 0.1 ml of raw milk into a tube. The end of the applicator stick is attached to a small balloon that contains pre-loaded chemistry. This chemistry is released by twisting the balloon to break a seal, which combines with the raw milk. The tube is agitated gently to mix the reagents, and then placed in a handheld luminometer. Readings are generated within 15 seconds. These assays were validated with >1,200 individual raw milk samples. The proteasome assay kit is fully compatible with a rapid cow-side diagnostic.

EXAMPLE 7

Non-Fluorogenic Substrates for Detecting Proteasome Activity

A set of approximately 12 non-fluorogenic substrates that required at least two different targeting pathways were described by Bachmair & Varshaysky ((1989) *Cell* 56:1019-1032). These reporter substrates contained the *E. coli* beta-galactosidase enzyme, and their degradation could be demonstrated in bacteria, human and metazoans (including human cultured cells). More recent derivatives include degradation substrates based on glutathione-S-transferase, and green fluorescence protein. Additionally, there are by now dozens, if not hundreds, of physiological substrates of the Ub/proteasome pathway. Access to the interior of the proteasome (which contains the three catalytic activities) is restricted by a narrow (13 angstrom) translocation channel.

EXAMPLE 8

Use of Antibodies to Measure Proteasome Abundance

Protein extract prepared from whole milk is incubated with GST-UbL SEPHAROSE (CELLXPLORE) to isolate catalytically active proteasomes. The UbL protein domain (isolated from human Rad23 proteins), forms a high-affinity interaction with catalytically active proteasomes. This efficient affinity matrix provides the only known way to isolate functional proteasomes within about 15 minutes. The activi-

26

ties of the proteasome can be determined while bound to the UbL matrix. The activity of the purified proteasomes is tested as described above. The beads are washed 3 times with 1 ml lysis buffer containing 1% TRITON X-100. Proteasome hydrolytic activity is measured on the immobilized proteasome. The immobilized proteins are separated in 10% SDS-tricine polyacrylamide gels, transferred to nitrocellulose, and antibodies used to detect the levels of Rpt1 and Rpn1 in the 19S regulatory particle, and the alpha-7 subunit in the 20S catalytic particle.

EXAMPLE 9

Antibodies Against Proteasomal Subunits

Antibodies against specific subunits are available commercially. By way of illustration, the antibodies listed in Table 2 are available from BIOMOL.

TABLE 2

Antibody Type	Species Reactivity						
		H	Y	Misc.	WB	IP	IHC
Antigen (clone)							
Rpn2 mAb (112-1)		X			X	X	
Rpn5 Rabbit pAb				AT	X		
Rnp6 Rabbit pAb				AT, CF	X		
Rpn7 Rabbit pAb		X	X		X		
Rpn8 Sheep pAb		X			X		X
Rpn10 mAb (S5a-18)		X			X	X	X
Rpn11 Rabbit pAb		X			X		
Rpn12 Rabbit pAb		X			X		X
mAb (p31-27)		X			X	X	X
mAb (31-38)		X			X	X	
Rabbit pAb				AT	X		

H, human;
Y, yeast;
AT, *Arabidopsis thaliana*;
CF, cauliflower;
WB, western blot;
IP, immunoprecipitation;
IHC, immunohistochemistry.

Antibodies that may be used in an immunoprecipitation (IP) reaction are expected to recognize the intact, functionally active proteasome. Note that Rpn10 and Rpn12 could both be used. Similarly, numerous alpha- and beta-subunits in the 20S catalytic particle may be targeted with antibodies for immunoprecipitation reactions. These antibodies can also be used in ELISA-based assays.

Alternatively, antibodies can be generated against one or more subunits of the proteasome and used in the assays herein. In this respect, two human proteasome subunits were cloned and purified and monoclonal against these subunits (Rpn8 and Alpha-6) were generated. Approximately 12-15 hybridomas were generated for each protein and cell lines expressing productive antibodies against the relevant proteasome subunits were identified. To facilitate their use in the instant assays, the hybridomas are screened to identify antibodies that recognize distinct parts in the target protein. A pair of non-overlapping antibodies is identified; one to affinity-purify the proteasome from raw milk and the second for use in determining the amount of proteasome that was recovered. Alternatively, antibodies against two different proteasome subunits are used to immunoprecipitate the proteasome and to detect the level that was recovered. Because antibodies were generated against two different proteins, multiple assays can be developed to produce one or more kits for detecting and

evaluating the severity of mastitis. Advantageously, the use of an antibody-based assay is economical, and no instrumentation is required.

EXAMPLE 10

Test-Strip for Antibody-Based Assay

A kit containing a solid support or test-strip can contain different amounts of an antibody that recognizes the proteasome. Microfluidics, lateral flow devices and in-line (real-time) sensors, are all amenable to this approach. Exposure of the strip to milk containing proteasomes (as in mastitis) results in binding to the immobilized antibody. The proteasome is then detected using a second antibody that recognizes the proteasome. However, the second antibody can be coupled to a label that permits detection. For example, conjugation of the second antibody to horse radish peroxidase (HRP) can be used to generate a colorimetric or chromogenic signal. However, the antibody could be conjugated to any enzyme whose activity can be measured. Alternatively, the second antibody can be coupled to a magnetic bead that can be detected by incubation with metal particles coated with FITC (for a fluorescence readout). Still further, the second antibody can be coupled to biotin, and the reaction developed using streptavidin conjugated to FITC or other easily detected fluorescence markers.

More specifically, a strip of nitrocellulose can be supported on a plastic matrix to provide stability and ease of use. A first antibody can be precisely deposited using simple robotic liquid handling devices. The filter is then blocked to prevent nonspecific interaction between proteins in the milk and the filter. The filter is then immersed in the milk sample to be tested. Incubation for a fixed duration is allowed to occur, e.g., 15 minutes, the filter is rinsed to remove milk, and a second antibody is incubated with the test strip to detect the presence of proteasomes. In one embodiment, the first and second antibodies bind to the same subunit, but to different epitopes. In this respect, the two antibodies would recognize the same proteasome subunit, but different regions in the three-dimensional structure. To facilitate detection, the second antibody can be coupled to a chromogenic substrate, biotin, or a reactive enzyme. The reaction is then detected by hydrolysis of a substrate that deposits a colored pigment, by binding of streptavidin that is conjugated to a chromogenic reagent, or exploiting the action of the attached enzyme to hydrolyze a substrate, respectively. Such reactions are routinely carried out in the art.

Alternatively, serial dilutions of antibody against one subunit of the proteasome can be deposited on a nitrocellulose strip. The filter is then immersed in the milk sample to be tested and incubated for a fixed duration, e.g., 15 minutes to capture proteasomes. The filter is then rinsed to remove milk, and incubated with an antibody that recognizes a different proteasome subunit. Because proteasomes remain intact in the presence of ATP, higher mastitis levels will be accompanied by more ATP in the milk, and more stable proteasomes. Thus, intact proteasomes can be recovered following the first antibody treatment, and detected using the second antibody. The two antibodies can recognize the same proteasome subunit, but different regions in the three-dimensional structure. To facilitate detection, the second antibody can be coupled to a chromogenic substrate, biotin, or a reactive enzyme. The reaction is detected by hydrolysis of the substrate that deposits a colored pigment, by binding streptavidin that is bound to a chromogenic reagent, or by exploiting the action of the enzyme to hydrolyze a substrate, respectively.

In yet another embodiment, whole (raw) milk could be directly incubated with a test-strip containing a small patch (or patches) of nitrocellulose, or other high-affinity protein binding surfaces. The strip would then be incubated with an antibody against a specific proteasome subunit, and detected as described above.

EXAMPLE 11

Test Samples

In some embodiments, the proteasome level is tested from samples obtained from a bulk storage tank containing milk from a plurality of animals. In other embodiments, the proteasome level is tested from samples obtained from a sample of milk from a single animal. Such samples may be tested as part of a routine testing program, or when the dairyman suspects that the animal may have an infection. In such cases, pre-clinical mastitis may be diagnosed prior to the appearance of any symptoms of inflammation and monitoring may be increased or the treatment of such animals may begin. Samples of milk from a single animal may be tested in cases where a diagnosis of mastitis has been previously made and treatment undertaken. Testing informs the dairyman if the animals condition has been resolved or if a low level infection persists. This ensures that treatment can be discontinued and animals may be prepared for return to the line as soon as they are ready but not prematurely when the risk of relapse is great.

EXAMPLE 12

ATP-Based Assay

As indicated herein, the stability of the proteasome is sensitive to ATP levels. Accordingly, ATP and ATPase activity are of use in detecting and monitoring pre-clinical and clinical mastitis. In accordance with this embodiment, the proteasome is rapidly affinity purified using GST-UbL. Raw milk is incubated with GST-UbL to isolate proteasomes. Excess milk is removed and the amount of proteasomes is determined by measuring enzymatic activity. The intact proteasome contains 12 subunits with ATPase activity. Therefore, the level of proteasome can be ascertained by measuring ATP hydrolysis by the purified complex. Purified proteasomes can be incubated in buffer containing a proteasome-specific substrate. These substrates can provide a chromogenic, fluorogenic or luminescent readout that typically monitor the release of ADP.

Alternatively, hydrolysis of ATP can deplete the amount available for a luciferase/luciferin-based luminescent assay. Accordingly, using conventional biochemical assays, it was determined whether ATP levels were detectable in milk. This analysis indicated that there was a substantial amount of ATP in milk. Therefore, it was determined whether ATP levels could be used as a surrogate for detecting mastitis. The assay proved to be highly successful, and provided a degree of sensitivity vastly in excess of current methods. As shown in FIG. 5, the enzyme luciferase can hydrolyse the substrate luciferin in an ATP-dependent reaction. The resulting reaction releases a photon of light that can be detected with a luminometer. Using a hand-held detector, the luminescent signal is readily detected and a lower signal is generated with increasing amounts of proteasomes in mastitis.

A kit for performing the assay can include a disposable container and a liquid holding spatula for collecting the milk sample. The milk sample is deposited into the plastic tube, and the spatula is secured in place. A plastic bulb attached to the spatula is twisted and squeezed to release the luciferase enzyme and luciferin substrate. Once combined with the milk sample, ATP is required for the reaction to proceed. The

reaction is linear over 4-orders of magnitude, and the ATP levels are proportional to the level of somatic cells in the milk. Thus, this assay provides a very rapid (minutes) evaluation of milk quality.

Measuring either ATP levels or ATPase activity is sensitive, linear, and quantitative; has a wide dynamic range; and has a low background signal.

EXAMPLE 13

Ubiquitin-Like Domain Affinity Matrix

Ubiquitin-like (UbL) domains from Rad23 proteins are known to bind the proteasome (Hiyama, et al. (1999) *J. Biol.*

Chem. 274:28019-28025; Schaubert, et al. (1998) *Nature* 391: 715-718). The UbL domains in two human Rad23 proteins form differential binding to proteasomes (Chen & Madura (2006) *FEBS Lett.* 580:3401-3408). To prepare UbL domain affinity matrices, UbL domains are expressed in *E. coli* as fusions to glutathione S-transferase (GST) or conjugated to beads. GST-UbL efficiently purifies catalytically active proteasomes from tissue extracts. Furthermore, regulatory factors that formed sub-stoichiometric interactions with the proteasome are also detected. See, Chen & Madura (2002) *Mol. Cell. Biol.* 22:4902-4913; Chuang, et al. (2005) *Mol. Cell. Biol.* 25:403-413; Leggett, et al. (2002) *Mol. Cell.* 10:495-507; Verma, et al. (2004) *Cell* 118:99-110.

SEQUENCE LISTING

<160> NUMBER OF SEQ ID NOS: 10

<210> SEQ ID NO 1
 <211> LENGTH: 8
 <212> TYPE: PRT
 <213> ORGANISM: Artificial sequence
 <220> FEATURE:
 <223> OTHER INFORMATION: Synthetic peptide
 <220> FEATURE:
 <221> NAME/KEY: MISC_FEATURE
 <222> LOCATION: (1)..(1)
 <223> OTHER INFORMATION: Blocked with succinimide
 <220> FEATURE:
 <221> NAME/KEY: MISC_FEATURE
 <222> LOCATION: (8)..(8)
 <223> OTHER INFORMATION: Conjugated to a detectable label.

<400> SEQUENCE: 1

Arg Pro Phe His Leu Leu Val Tyr
 1 5

<210> SEQ ID NO 2
 <211> LENGTH: 4
 <212> TYPE: PRT
 <213> ORGANISM: Artificial sequence
 <220> FEATURE:
 <223> OTHER INFORMATION: Synthetic peptide
 <220> FEATURE:
 <221> NAME/KEY: MISC_FEATURE
 <222> LOCATION: (1)..(1)
 <223> OTHER INFORMATION: Blocked with succinimide
 <220> FEATURE:
 <221> NAME/KEY: MISC_FEATURE
 <222> LOCATION: (4)..(4)
 <223> OTHER INFORMATION: Conjugated to a detectable label.

<400> SEQUENCE: 2

Leu Leu Val Tyr
 1

<210> SEQ ID NO 3
 <211> LENGTH: 4
 <212> TYPE: PRT
 <213> ORGANISM: Artificial sequence
 <220> FEATURE:
 <223> OTHER INFORMATION: Synthetic peptide
 <220> FEATURE:
 <221> NAME/KEY: MOD_RES
 <222> LOCATION: (1)..(1)
 <223> OTHER INFORMATION: ACETYLATION
 <220> FEATURE:
 <221> NAME/KEY: MISC_FEATURE
 <222> LOCATION: (4)..(4)
 <223> OTHER INFORMATION: Conjugated to a detectable label

<400> SEQUENCE: 3

-continued

Gly Pro Leu Asp
1

<210> SEQ ID NO 4
<211> LENGTH: 4
<212> TYPE: PRT
<213> ORGANISM: Artificial sequence
<220> FEATURE:
<223> OTHER INFORMATION: Synthetic peptide
<220> FEATURE:
<221> NAME/KEY: MOD_RES
<222> LOCATION: (1)..(1)
<223> OTHER INFORMATION: ACETYLATION, Nle
<220> FEATURE:
<221> NAME/KEY: MOD_RES
<222> LOCATION: (3)..(3)
<223> OTHER INFORMATION: Nle
<220> FEATURE:
<221> NAME/KEY: MISC_FEATURE
<222> LOCATION: (4)..(4)
<223> OTHER INFORMATION: Conjugated to detectable label.

<400> SEQUENCE: 4

Leu Pro Leu Asp
1

<210> SEQ ID NO 5
<211> LENGTH: 20
<212> TYPE: RNA
<213> ORGANISM: Artificial sequence
<220> FEATURE:
<223> OTHER INFORMATION: Synthetic oligonucleotide

<400> SEQUENCE: 5

auuuauuuu auuuauuuu

20

<210> SEQ ID NO 6
<211> LENGTH: 4
<212> TYPE: PRT
<213> ORGANISM: Artificial sequence
<220> FEATURE:
<223> OTHER INFORMATION: Synthetic peptide
<220> FEATURE:
<221> NAME/KEY: MOD_RES
<222> LOCATION: (1)..(1)
<223> OTHER INFORMATION: ACETYLATION, Nle
<220> FEATURE:
<221> NAME/KEY: MOD_RES
<222> LOCATION: (3)..(3)
<223> OTHER INFORMATION: Nle

<400> SEQUENCE: 6

Leu Pro Leu Asp
1

<210> SEQ ID NO 7
<211> LENGTH: 4
<212> TYPE: PRT

-continued

<213> ORGANISM: Artificial sequence
<220> FEATURE:
<223> OTHER INFORMATION: Synthetic peptide
<220> FEATURE:
<221> NAME/KEY: MOD_RES
<222> LOCATION: (1)..(1)
<223> OTHER INFORMATION: ACETYLTATION

<400> SEQUENCE: 7

Gly Pro Leu Asp
1

<210> SEQ ID NO 8
<211> LENGTH: 8
<212> TYPE: PRT
<213> ORGANISM: Artificial sequence
<220> FEATURE:
<223> OTHER INFORMATION: Synthetic peptide
<220> FEATURE:
<221> NAME/KEY: MISC_FEATURE
<222> LOCATION: (1)..(1)
<223> OTHER INFORMATION: Blocked with succinimide.

<400> SEQUENCE: 8

Arg Pro Phe His Leu Leu Val Tyr
1 5

<210> SEQ ID NO 9
<211> LENGTH: 4
<212> TYPE: PRT
<213> ORGANISM: Artificial sequence
<220> FEATURE:
<223> OTHER INFORMATION: Synthetic peptide.
<220> FEATURE:
<221> NAME/KEY: MISC_FEATURE
<222> LOCATION: (1)..(1)
<223> OTHER INFORMATION: Blocked with succinimide.

<400> SEQUENCE: 9

Leu Leu Val Tyr
1

<210> SEQ ID NO 10
<211> LENGTH: 5
<212> TYPE: PRT
<213> ORGANISM: Artificial sequence
<220> FEATURE:
<223> OTHER INFORMATION: Synthetic peptide
<220> FEATURE:
<221> NAME/KEY: MISC_FEATURE
<222> LOCATION: (5)..(5)
<223> OTHER INFORMATION: Conjugated to detectable label.

<400> SEQUENCE: 10

Arg Leu Arg Gly Gly
1 5

35

What is claimed is:

1. A method for determining proteasomal activity in milk from an animal indicative of mastitis in the animal, said method comprising

- (a) contacting a test sample of milk collected from the animal with luciferase and luciferin; 5
- (b) determining a level of adenosine triphosphate (ATP) present in the test sample by detecting hydrolysis of luciferin; and
- (c) comparing the level of ATP with a standard level of ATP 10 in a control sample of milk, wherein a lower level of ATP present in the test sample relative to the control sample is indicative of elevated proteasomal activity and mastitis in the animal.

* * * * *

15

36